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ABSTRACT

At the same time that educators and researchers are identifying ways in which major reform and restructuring is needed in schools, research on student learning in science (and other subjects) from constructivist and conceptual-change perspectives is suggesting the potential for significant improvements in students' understanding of science and science concepts. The focus of the study was the role of writing and classroom discourse in supporting student understanding in science. This topic was explored across 4 months of fifth grade science instruction designed to promote students' conceptual change, using daily observations of teaching, analysis of student writing, teacher reflections, and interviews with students to trace student thinking and the role that writing and discourse play in student learning. Working collaboratively as part of an effort to create a school-university professional development school, the researchers in this study included university teachers and elementary school teachers. This paper presents a description of six student's writing during one unit of instruction, and a description of one lesson segment that illustrates the relationship between private writing and public discourse in this science classroom. Discussion focuses on the roles that writing played from both the teachers perspective and the students' perspectives and the contributions that writing made to the development of a science-learning community in this classroom. (PR)

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THE ROLE OF WRITING IN CREATING A SCIENCE LEARNING COMMUNITY

Kathleen J. Roth
with
Literacy in Science
and Social Studies Colleagues

Center for the Learning and Teaching of Elementary Subjects

Institute for Research on Teaching

College of Education

Michigan State University

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Kathleen J. Roth
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and Barbara Lindquist

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Abstract

At the same time that educators and researchers are identifying ways in which major reform and restructuring is needed in schools, research on student learning in science (and other subjects) from constructivist and conceptual-change perspectives is suggesting the potential for significant improvements in students' understanding of science and science concepts. This study represents an intersection between a school-reform effort and a classroom study of science teaching and learning. Working collaboratively as part of an effort to create a school-university professional development school, the researchers in this study included university researchers and elementary school teachers. The teachers' professional time was restructured so that they were teaching half time and participating in research and teacher-education efforts half time. The focus of the research team's study was teaching and learning in a fifth-grade science classroom. The teacher in this classroom was a university science-education researcher. Thus, the study explored a research approach in which researchers took on teacher roles and teachers took on researcher roles.

The focus of the study of this team of teacher-researchers was the role of writing and classroom discourse in supporting student understanding in science: What roles do writing and discourse play in promoting science understanding? This question was explored across four months of instruction designed to promote students' conceptual change, using daily observations of teaching, analysis of student writing, teacher reflections, and interviews with students to trace student thinking and the role that writing and discourse played in student learning. The collaborative nature of the research led to the development of a new research direction as the study progressed: What kind of learning community is needed to support learning in science? What role does writing play in creating a learning community in science classrooms? The paper presents both a contextual and a theoretical framework for the study, a description of six students' writing during one unit of instruction, and a description of one lesson segment that illustrates the relationship between private writing and public discourse in this science classroom. Discussion focuses on the roles that writing played from both the teacher's perspective and the students' perspectives and the contributions that writing made to the development of a science-learning community in this classroom.

THE ROLE OF WRITING IN CREATING A SCIENCE LEARNING COMMUNITY

Kathleen J. Roth with Cheryl Rosaen, Corinna Hasbach, Constanza Hazelwood, Kathleen Peasley, Elaine Hoekwater, and Barbara Lindquist[1]

At the same time that educators and researchers are identifying ways in which major reform is needed in schools, research on student learning has revealed students' tremendous potential for understanding concepts and using skills required to participate fully as literate members of society (Ball, 1990; Bereiter & Scardamalia, 1987; Driver, 1987; Lampert, 1988; Lemke, 1988; Michaels & O'Connor, 1990). When research on teaching for understanding in the various subject matter areas is shared with practicing teachers, it is not uncommon to hear comments like the following:

"That sounds great for those kids, but the kids in my class would never be able to do that."

"OK, let's go back to reality now."

"Are these kids gifted?"

"My kids don't know enough to have a discussion like that."

"My students would never be that interested in a topic like where food for plants comes from."

"How did the kids sit through such a long discussion without misbehaving?"

"Who was watching those kids who were working independently while the teacher had a conference with one student?"

"I can't picture my children talking to each other about science like that."

"I don't understand math well enough to lead that kind of discussion."

In many ways these questions and comments can be discouraging to researchers because they point out the painful reality that mere research findings do not necessarily inform or support

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ways to bring about change in classroom teaching practices. As a university researcher I became interested in finding ways to conduct classroom research in collaboration with experienced teachers so that researchers could move beyond the role of outsiders coming in to tell teachers what research has to say about classroom teaching. I am convinced that classroom teachers can and should share in the role of developing new knowledge that will inform and suggest ways to improve teaching practice; researchers and classroom teachers can join together to do research for teaching (Cochran-Smith & Lytle, 1990; McLaughlin, 1990; Noddings, 1986; Power, 1990). Two years ago I began working with a group of educators that included two university researchers, three doctoral students, and three classroom teachers in a project called Literacy in Science and Social Studies (LISSS). In this project we have been exploring ways to teach for understanding in science and social studies, with an emphasis on studying ways in which discourse and writing can be used effectively to promote understanding.

In the second year of the project, the group participants each took on a teacher-researcher role to learn new ways to study students' thinking in a classroom setting and to study our own teaching practice.[2] In Barbara Lindquist's fifth-grade classroom, I taught science in the fall while Lindquist assisted in data collection and reflection on I teaching. We investigated what is possible in terms of student learning when a conceptual change model of teaching science[3] is used consistently across time and the role writing could play in teaching for understanding in science. This line of inquiry was undertaken to investigate the following:

a. What are the kinds of understandings, skills, and dispositions students can develop over time when a conceptual change model is used to guide science instructional planning and teaching?

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[2]Due to space limitations, this paper only discusses the teacher-researcher roles that two of the eight project participants took on. The first author wants to acknowledge joint contributions of all project participants in developing the ideas regarding learning community and teaching for understanding that are discussed in this paper.

[3]Ways in which we conceptualized this model and its research base will be described in greater detail later in the paper.

b. What are the strengths, gaps, or problems of a conceptual change model in action in ordinary classrooms?

c. What roles do writing and discourse play in promoting science understanding?

d. What kind of learning community is needed to support learning in science?

e. What role does writing play in creating a learning community in science classrooms?

This paper focuses primarily on the findings regarding the role of writing activities in the creation of a science learning community and in the development of students' understandings about science and science concepts. The paper begins by placing this study in two contexts: A collaborative context in which teachers and researchers explored a new vision of educational research and a theoretical context that draws from studies of constructivism and conceptual change in science learning. The collaborative context enabled the development of a shared teacher and researcher vision of a learning community that will support teaching for understanding in science (and other subjects).

Collaborative Context: A Shared Vision of a Learning-Centered Classroom

Although I came into this fifth-grade classroom with the intent of studying the role of writing in conceptual change science teaching, the collaborative nature of the work helped me place this goal in the context of a vision of a learning-centered classroom. Through shared work with the fifth-grade students in the classroom and through weekly study group sessions, the LISSS Project participants came to see the importance of creating a classroom environment that differed in striking ways from traditional classrooms (our classrooms in the past!). We developed two metaphors for describing the kind of learning environment we were trying to create. These metaphors were helpful in both creating and analyzing the kinds of experiences that would help all students develop significant understandings in science and other subject areas.

A Learning Place vs. a Workplace

The first metaphor was taken from Hermine Marshall's (1990) distinction between the classroom as a workplace compared to a the classroom as a learning place. We extended and elaborated Marshall's metaphor and created a list of qualities that are important to us and that

contrast with more traditional, work-oriented classrooms (which sometimes included our own classrooms in the past, see Table 1).

These two metaphors illustrate a tension, rather than a distinct dichotomy, since it must be acknowledged that all students complete work of some kind in any type of classroom setting. An important contrast between these two metaphors is in what is communicated to students to be valued and worthwhile--the difference in relative emphasis on completing assignments and on learning. In the work-oriented setting, the need to complete the work tends to overshadow attention to actual learning. In the learning-centered classroom, students still complete work, but there is an important focus on how and why the work is being done. Thinking, questioning, discussing, making mistakes, trying new ideas, and so forth, are valued and rewarded as much as completing a finished product. As teachers design and carry out activities in a learning-centered classroom, they need to pay attention to ways in which each activity potentially and actually contributes to qualities they want to foster in the larger learning community.

An Elegantly Simple Metaphor

Elaborating the qualities of a learning-centered classroom was an important step in articulating our shared vision for our classrooms. We were still searching, however, for an image that would more specifically communicate our goals of teaching for understanding and capture the nature of the learning community we were attempting to create. Over the course of several weeks of reading, discussing, considering, and rejecting many different metaphors, our group discovered an elegantly simple image that seemed to represent perfectly our shared vision of the kind of classroom we are striving for--the Amish nine-patch quilt (see Figure 1). At first the quilt looked too simple to represent the complex undertaking of teaching for understanding in a learning community. But one of our group members, Carol Ligett, helped us persist in understanding aspects of quilting as a process and a product that helped us reconsider and eventually become very excited about the power of this metaphor.

We offer a brief look at the nine-patch quilt and the quilting process to elaborate and explain our metaphor:

Table 1

A Learning Setting vs. a Work Setting:
Creating a Conceptual Change Learning Community

A CONCEPTUAL CHANGE SCIENCE LEARNING COMMUNITY	A WORK-ORIENTED CLASSROOM SETTING
*Sense making and learning as the goal	*Getting the work done as the goal; getting facts learned or activities and projects completed
*Personal, emotional involvement in meaningful and authentic problem situations	*Depersonalized, unemotional relationship with work, getting the products made
*Ownership and commitment by each person; responsibility shared	*Teacher as executive in charge of everything
*Active inquiry and question-asking are valued and encouraged	*Getting the right answer is valued and encouraged
*Expertise comes from everyone, is shared; learning is a collaborative process	*Expertise comes from the teacher and learning is a private activity
*Everyone's ideas are valued and respected as useful in the learning process; diversity is celebrated in a caring environment	*Workers need to keep quiet and busy; diversity is a problem for quality control and efficiency
*Good learners listen to each other	*Good workers listen to the teacher
*Public sharing and revising (working out) of ideas	*Only complete, polished final products are shared
*Evidence, not authority, is used to construct new knowledge and judge merits of ideas	*Knowledge comes wrapped in neat packages that are delivered from teacher or text to student; all packages are to be appreciated and not questioned
*Each learner starts and finishes in a unique place; learning as a process of conceptual change	*All workers create the same product or else are failures; learning as a "you have it or you don't" phenomena

NOTE: The metaphor of a learning vs. a work setting for thinking about classrooms was adapted from Hermine H. Marshall (1990) in "Beyond the Workplace Metaphor: The Classroom as a Learning Setting" in Theory Into Practice, 29, 94-101.

Figure 1. An Amish nine-patch quilt.

Reprinted with permission form Threads Magazine: Sue Bender, "Amish Quiet, Amish Quilt," Number 30, August/September, 1990.

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The top layer of the quilt has patches that represent for us the various units we teach in our classrooms--the series of interrelated activities we engage in with students over time. Each of these patches may look very colorful and independent, but alone they do not contribute to making a quilt--to helping students construct understanding--unless they are connected in several ways.

The middle layer (batting): Underneath the patches is the batting, which provides the substance, the warmth of the quilt. To us, this batting represents the big ideas and methods of inquiry in the disciplines from which our units are drawn. If our units are not backed by such important ideas, the patches--the units made up of activities--will not have any function, any meaning. But the patches and the depth, the batting, still do not make the quilt.

The backing and quilting stitches: The patches and batting are held together by a backing and by many tiny, intricate quilting stitches. The stitches represent the qualities of the learning place we list above (Table 1). Without this backing and the many tiny, consistent stitches, the quilt would fall apart. It would not only lose its function, it would lose much of its beauty, for the tiny stitches that go through all three layers of the quilt to form the beautiful patterns are not random. We think of the backing of the quilt as the learning community in our classrooms and the stitches as the qualities of the learning setting that are created over time as students and teachers engage in learning activities together. People visiting our classrooms need to look for tiny stitches to appreciate the qualities of our learning environment: The feedback students receive from their teacher on written work; the encouragement to ask questions and to make sense instead of just finishing work or memorizing facts; the care put into teacher questions and activities to communicate sense-making and meaning; the ways in which student ideas are listened to and brought into the fabric of the classroom; and the encouragement and support students are given to forge new connections and patterns.

The quilters: The teachers and students are the quilters who work together to put these patches together patiently over time using consistent, tiny stitches. We as teachers consistently try to communicate--through our actions and the activities we choose--that this is a collaborative learning setting.

The finished quilt: In our metaphor the warm, finished quilt with its patches and intricate stitching patterns represents the quality of understandings that children develop.

The quilting process: Like many quilters, we are working on our quilt together, patiently over time. This represents an appreciation of the importance of the quilting (or learning) process--the interaction, reflection, collaboration--as well as the finished product. Also like quilters, we are never sure our quilt is finished completely; we reserve the right to go back and rearrange the patches or restitch an area. This parallels the tentative nature of knowledge and the need to revisit and revise our thinking as members of the classroom learning community.

This image of teaching and learning is an alternative view of the typical notion of the teacher as someone who imparts knowledge or skills to students, and it rests on a fundamentally different relationship among teacher and students. Instead of imparting knowledge, teaching for understanding is geared toward empowering and enabling learners to construct their own meaning

so that the learning is relevant and useful, and so that learners know how to go on learning. This notion of teaching and learning requires a shift in the roles of teachers away from the workplace environment where the teacher is the holder of knowledge who "gives" it to the students through assigned work, and the students produce the work that supposedly shows they learned the knowledge given. A learning-place environment requires a particular kind of social context that enables learners to practice and exercise particular kinds of actions (inquiry, questioning, collaborating, etc.) surrounding knowledge that is connected and useful.

Theoretical Context: Learning in Science

In Lindquist's fifth-grade science classroom I attempted to establish a learning setting that was organized around a conceptual change model of instruction. This section describes a two-way interaction between the research base and my classroom teaching.

The Conceptual Change Research Base

Research has uncovered the powerful role that students' experience-based conceptions of natural phenomena (alternatively called naive theories, personal theories, intuitive conceptions, alternative frameworks, misconceptions, etc.) play in the learning process. While psychological research on children's ways of thinking continues to explore how students make sense of their experiences with light, plants, living things, gravity, electricity, blood circulation, day and night, and so forth, science educators are investigating ways in which this knowledge can be used instructionally. Instructional models based on this research have viewed science learning as a process of conceptual change, in which learners enter instruction holding a wealth of ideas about scientific phenomena that contrast in many ways with accepted scientific explanations. To support students in changing these conceptions to more productive and useful scientific conceptions, instruction must take the students' entering conceptions seriously and support students in revising and reconstructing their explanations.

This body of research (Hewson & Hewson, 1984; Johansson, Marton, & Svensson, 1985; Posner, Strike, Hewson, & Gertzog, 1982; West & Pines, 1985) and my own investigations as a researcher have had a significant impact on the ways I define goals for my students and approach

my science planning and teaching. First, my role as a researcher of student thinking and learning in science raised my awareness of the unfortunate kinds of understanding many students seem to be developing in science classes: that science is only for elite students, that science is not something that makes sense, that science has little to do with everyday life outside school, that good learners of science can memorize lots of definitions and formulae, that science is a straightforward uncovering of facts, that scientific knowledge resides in the minds of experts who have all the answers, and so forth. In contrast with this view of science, I wanted my students to develop connected and useful understandings of science concepts and to develop dispositions to reflect and act on scientific knowledge. Table 2 summarizes the key characteristics of scientific understanding that represented my broad goals for science instruction.[4]

Table 3 illustrates the conceptual change framework that served as an explicitly defined guide to my instructional decision making when I began teaching these fifth graders in September 1990. As this framework shows, I viewed science instruction as beginning with the establishment of a problem: How does light help us see? Why are summers hot and winters cold? How do plants get their food? Are there more different plant and animal species in the desert or in Michigan? By eliciting students' ideas about the problem, by challenging students' personal theories, and by encouraging debate and a search for evidence to support differing views, I try to engage students in genuine involvement with a problem. This engagement results in a lot of wondering, questioning, and challenging of ideas and creates "cognitive conflict" (Piaget, 1969) and puzzlement:

> "I didn't think deserts had any plants except a few cactus, but they do have flowers and trees, so maybe there are as many different species as in Michigan."
>
> "How could we ever prove whether deserts have more or fewer species than Michigan?"
>
> "How could there be plants on the desert--don't they need water?"

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[4]These characteristics of scientific understanding were developed in collaboration with Charles W. Anderson.

"Maybe there's more different kinds of plants and animals on the desert, but there's greater numbers of each species in Michigan."

"I don't believe those animals could survive on the desert. No one would want to live on the desert--it's too hot!"

"If plants don't use soil for food, then what is their food?"

"Water doesn't have food energy, but plants have to have water to grow. So doesn't water give them food?"

"Why would they call fertilizers 'plant food' if it's not food?!"

Scientific concepts (about photosynthesis, adaptations, species diversity) are presented in ways that support students in contrasting them with their own ideas and in using the new ideas repeatedly to explain real-world phenomena with which students are familiar. As students work with these new ideas over time, the teacher scaffolds their efforts with modeling and gentle coaching of scientific thinking. The goal, however, is for students to use new ideas and to connect new ideas to other concepts without teacher support. Therefore, the teacher strives to fade out of the coaching role as soon as possible. In this model of instruction, teacher and students stick with a problem for a relatively long period of time--long enough to consider evidence supporting or challenging a variety of proposed explanations, to explore student-generated questions and ideas, to try using new scientific conceptions to explain a variety of natural phenomena, and to make sense of how personal theories do or do not fit with scientific explanation.

A Changing View of a Conceptual Change Model of Instruction

In my own research and teaching and in research by others (Driver, 1987; Linn, 1989; Minstrell, 1984), I was struck by the power of this instructional model to help students develop a deeper, more meaningful understanding of science. For example, in an earlier study I taught a fifth-grade class science and social studies across the 1988-89 school year using such a conceptual change approach. That study provided compelling evidence that a conceptual change framework for planning and teaching helped students develop rich understandings of science concepts. Even students with reading difficulties and low interest in school developed connected and useful understandings as well as dispositions to question and make sense of natural phenomena.

Table 2

Characteristics of Scientific Understanding

I. CONNECTEDNESS OF KNOWLEDGE

- A. Connections among science concepts and theories
- B. Connections of science concepts and theories to prior knowledge and "real world" knowledge

II. USEFULNESS OF SCIENTIFIC KNOWLEDGE in activities that scientists and scientifically literate persons engage in

- A. Description of real-world phenomena
- B. Explanation of real-world phenomena
- C. Prediction of real-world phenomena
- D. Design of real-world systems or phenomena
- E. Appreciation of real-world phenomena--the wonders, beauties, complexities of the natural world

III. DISPOSITION TO REFLECT AND ACT ON SCIENTIFIC KNOWLEDGE BY

- A. Testing or justifying beliefs on empirical or theoretical grounds--looking for "best" sources of evidence
- B. Criticizing arguments on empirical or theoretical grounds--having the disposition to critically evaluate arguments
- C. Viewing knowledge as constantly changing, building, deepening over time
- D. Recognizing limits to knowledge
- E. Constructing new knowledge by asking appropriate questions, developing solutions to problems using personal knowledge and reasoning, empirical investigations
- F. Interacting with other people to develop new understandings; valuing such interactions as an important aspect of the scientific community

Table 3

A Conceptual-Change Model of Instruction

Establishing A Problem

*Eliciting Students' Ideas About a Natural Phenomenon

Students should see that other students have different ways of explaining the same phenomenon.

*Challenging Students' Ideas to Create Conceptual Conflict, Dissatisfaction

Engage students in thinking through whether there is evidence for their ideas and whether their ideas really make sense. For example, have students make predictions and then read or do a laboratory activity to find out if their predictions are correct or not. Encourage students to debate among themselves.

*Contrasting Students' Naive Explanations and Scientific Explanations

Explain and/or introduce new condepts in ways that are likely to make sense from the students' perspectives. Use a variety of different representations to explain new ideas (models, role playing, explanations, charts, diagrams, etc.). Compare/contrast students' ideas with scientific explanations.

Understanding And Using Scientific Concepts

Students need numerous opportunities to use new concepts to explain real-world situations. A variety of activities and questions that engage students in using scientific concepts and in refining their understandings of these concepts will help students see the wide usefulness of the concepts. At first, students' misconceptions will persist as they answer these questions. The teacher, therefore, must play the role of "cognitive coach" (Collings, Brown, and Newman, 1986), helping students develop better strategies for comprehending concepts and explaining phenomena by

a. modeling appropriate strategies
b. coaching students as they try to use the strategies
c. scaffolding the students' efforts to use the strategies
d. gradually fading the amount of teacher direction and guidance in constructing explanations for these questions

For example, Sherrie[5], a quiet and timid student who received resource room support for reading, was undaunted by a concept-mapping activity at the end of the year that asked her to show the connections among 36 main science concepts we had studied across the year. Sherrie was able to construct confidently her personal concept map and to explain it in a way that reflected a comfort with the concepts--that the concepts were her own, not memorized words from a text or the teacher's mouth. Even a year later, at the end of sixth grade, students like Sherrie were able to complete this task with comfort and confidence. They were also able to use ideas we had studied to explain new observations and even to answer their own questions. Their disposition to inquire and make sense was reflected in the quality and quantity of questions they contributed in class and in our class Question Notebook across the year, but it was even more dramatically reflected in comments made by students and parents during nonclass hours:

> John: [passing by the plants on his way to lunch] You know, Ms. Roth, I used to think plants just kind of sit there. But they're really busy little things aren't they?
>
> Brenda: [helping to clean up the room at the end of the year, while taking down the time line we had constructed for social studies] You know, Ms. Roth, all those things we studied in science . . . they all fit together in the end, didn't they?
>
> A Parent: We were out working in the yard and Trina started talking about this huge tree and that it was doing photosynthesis and explaining it all to us. She was wondering about how <u>much</u> water it needed to do photosynthesis.
>
> A Parent: We were watching TV and TJ started questioning an advertisement about some medicine. He was trying to figure out if it could start acting as fast as the advertisers were claiming.

What aspects of conceptual change teaching enabled so many students to become successful learners in science? I did not believe that I had found a magical set of activities that were the perfect ones to challenge students to rethink their naive theories. Although I did try to use appropriate discrepant events that would capture students' imaginations, the activities themselves did not seem to be the critical factor. Rather, a more critical aspect of the classroom activities seemed to me to be the kinds of writing and talking that surrounded these activities and that created a classroom community of inquiry and learning. I decided to study this aspect of conceptual

[5]Names of all students are pseudonyms.

change teaching while teaching my fifth graders in Fall 1990.

I began in Fall 1990 using the conceptual change framework outlined in Table 3. This model continued to be a helpful guide to me, but my ideas about the model changed. My close collaboration with the LISSS Project members, including the classroom teacher, Lindquist, enabled me to identify gaps in the model that were not apparent to me when I conducted the more solitary study of my own teaching in 1988-89. As Lindquist observed, documented, and reflected on my teaching, she kept insisting that it was not the activities themselves that seemed so strikingly different. She noted how hard it is for an outsider to come in and immediately see the richness of the students' experience and how it contrasts with more traditional teaching. As a daily participant/researcher in the classroom she could see what might otherwise be invisible--the patient stitches that the students and I were making across time that enabled us in the long run to piece together a beautiful quilt: understanding. Lindquist would comment on ways in which she could imagine herself or other teachers doing the very same activities but with very different results. She observed how her student teacher had used "my" conceptual change activities and curriculum materials but failed to get kids engaged in questioning and puzzling about phenomena.

At first these observations bothered me. Were we going back to saying that some teachers "have it" and some don't? This did not make sense to me. I did not believe that it was just that I had some sort of intuitive connection with kids. After all, I taught for many years without experiencing this kind of success in terms of student learning and understanding. Clearly, I had learned something from the conceptual change research that was making a difference in my teaching. But what was I doing that was not captured in the conceptual change model I was using?

This line of questioning and analysis helped me make explicit many assumptions that had been previously implicit in my view of a conceptual change model. What was obvious to me in that model but not communicated to others? The conceptual change model that I was using does not address the importance of creating a social context--a learning community of scientific inquiry--that will enable the eliciting, challenging, and contrasting to support students in developing connected, useful, and reflective understandings of science. Without such a learning community,

the conceptual change framework could be interpreted as "Find out how students are wrong and often funny, make them feel bad about being wrong, and show them how far off their ideas are. Then make sure they never use their own ideas again but only use the scientific concepts." Obviously, this is an exaggeration, but it shows how the conceptual change framework without the appropriate social context could promote mistaken notions about the nature of science and scientific inquiry (that there is always one right explanation, that scientific ideas are always more valued than personal ideas, that personal ideas have no place in scientific inquiry, etc.). The aspects of the learning community that I have found to be critical stand in contrast with usual standards of a well-run, efficient, businesslike classroom. Some of these aspects are listed in Table 1.

As I now think about the conceptual change model of instruction, what I used to think of as the model--eliciting and challenging students' ideas, contrasting students' ideas with scientific explanations, providing multiple opportunities for students to use concepts to explain real-world situations--is now just a piece of the model, a piece that has no meaning (or, using the quilt metaphor, no beauty) unless it is carefully connected with children and their ideas in a learning community that encourages and enables active inquiry and sense making. One way of representing my new vision of the model is to envelop the model in a learning environment needed to support learning versus just getting work done (see Figure 2).

The Study: Research Questions, Methods, and Analysis

Research Questions

The study was undertaken to explore the roles that writing and classroom discourse play in promoting science understanding when a conceptual change approach to science instruction is used. As the study progressed, the importance of the learning community emerged and led to a new slant on the research focus: What kind of learning community is needed to support learning in science? What role does writing play in creating a learning community in science classrooms?

Teacher/Researcher Roles

In this study I assumed a teacher-researcher role, teaching science to a group of fifth graders from August through December 1990 and studying my teaching practice and my students'

writing, talking, and learning across that time. I was supported in the research process by Lindquist, the students' regular teacher, and by other LISSS project participants. Lindquist was in the classroom daily as I taught science, and she assisted the data collection process by taking field notes, running the video camera, and talking with students. Hazelwood observed the class frequently (two to three times per week over the four-month period) taking field notes and/or videotaping target groups of students. Hazelwood also conducted interviews with students. Other LISSS participants (Ligett, Hoekwater, Hasbach, Peasley, and Rosaen) assisted the research process in weekly study group sessions, examining with us samples of student writing, videotapes of lesson segments and student interviews. In addition to this support in the analysis process, the study group played a role in the the development of interview questions, the definition and refocusing of research questions, and the generation of research strategies.

The Students

The 22 fifth-grade students in this classroom lived in a community that was changing as the adjacent midsize city sprawled outwards. The predominantly rural, blue-collar community was slowly becoming more of a suburb to the city, with new subdivisions being built that attracted more professional and paraprofessional families. While most of the parents of the students in Lindquist's class had not attended college, two parents were professionals (one a physician and the other a high-level civil servant). This elementary school is considered to have the highest number of at-risk students of the five elementary schools in the district. Many students in this school live in a neighboring trailer park and are living on low family incomes. The 22 students in this classroom included one mainstreamed special education student, four older students who had repeated a grade, two students pulled out for speech therapy, and a number of students who had been on the Chapter I reading-resource teacher's load (only one was currently seeing the reading teacher at the time of this study). While the students represented the usual range of academic abilities, Lindquist noted that this class had lower achievement test and IQ scores than previous classes. Racially, the class reflected the community composition, with 17 Caucasian students, 1 African American student, 3 Hispanic students, and 1 student of Native-American descent.

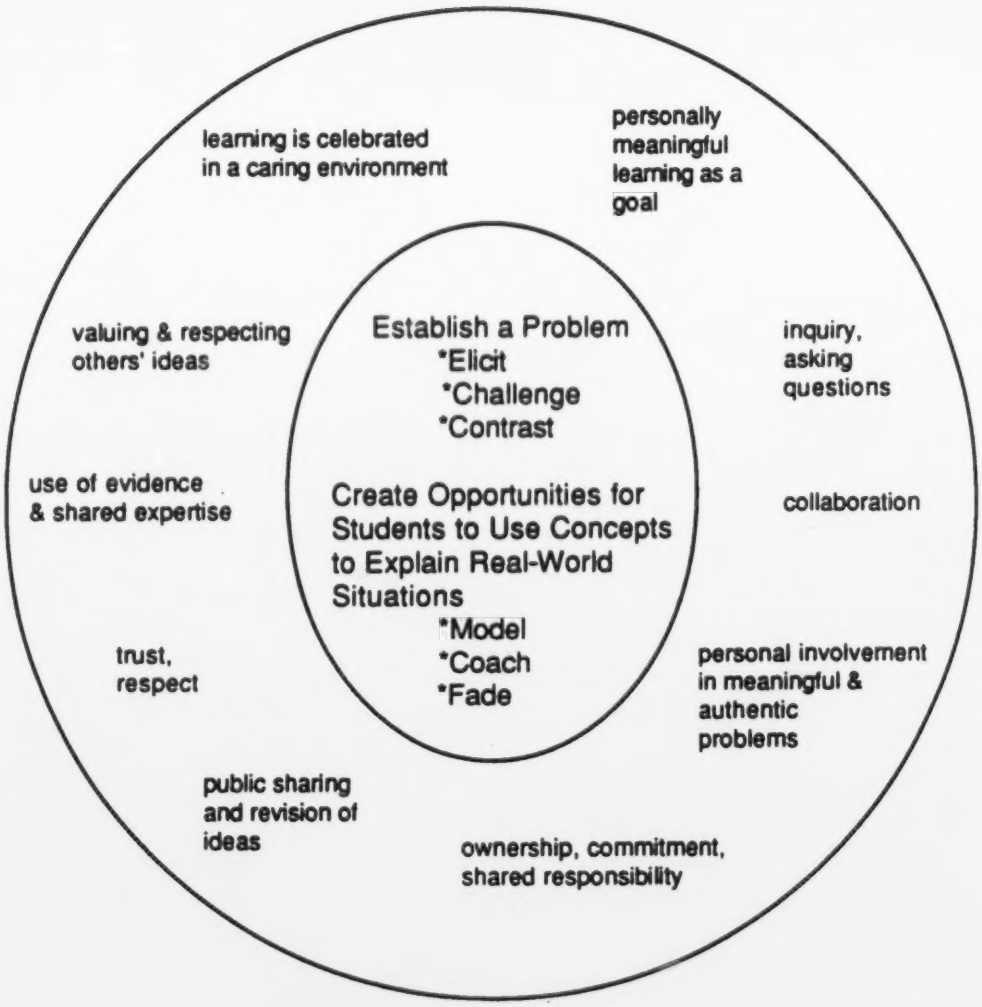

Figure 2. A conceptual change science learning community.

Target Groups

To enable us to examine the relationship between writing and discourse during the small-group activities in this classroom, we selected two target groups of students. At the beginning of the year the target groups included one group of four girls and one group of four boys. These were groups that the students had self-selected on the first day of school. On that first day of school, some of the students sat with long-time friends while others found themselves grouped with students they had never interacted with before. An important factor in the seating arrangement was that students had selected to sit with gender-mates. Each group included students with a wide range of abilities and academic success. In the target girls' group, for example, two of the girls were resource-room students (for speech and reading, respectively), while another girl was one of the stronger academic students in the class. In November the groups were changed. The teacher/research team chose two new target groups, each of which had at least two students who had been in the original target groups; and each group included two girls and two boys. Although all 22 students were studied during whole-class discussion and while writing, the target groups were the focus of study during small-group discussions and activities.

Data Sources

Each lesson across the four-month period was tape recorded. Two tape recorders were used, with each one placed in the midst of a target group. During the photosynthesis unit, daily lessons were video- and audiotaped. During the whole-class discussions, one camera focused on the class as a whole while the other camera focused on one of the target groups. During group work, the cameras focused on the two target groups. Field notes were taken by Lindquist and/or Hazelwood for most lessons. All student writing (including journals, class charts, and writing in the Food for Plants II (Roth, 1988) text/workbook, posttests for the adaptations/scientific inquiry unit, pretests and posttests for the photosynthesis unit) was collected. Teacher reflections on the teaching and learning process were captured in a teacher journal and in audio recordings of postlesson conversations with Lindquist, Hazelwood, classroom visitors, and other LISSS project

participants. In addition, teacher reflections and insights are captured in the teacher-written reports about each student sent to parents at report card time.

Interviews with students in the target groups were conducted in the middle of the term (October) and at the end of the school year (May-June). These in-depth interviews probed students' understanding of the science concepts they were studying, their perceptions of science and scientists, and the roles that writing and classroom discourse played in their learning. All students participated in mini-interviews at the end of the photosynthesis unit (December). These mini-interviews probed students' understanding of photosynthesis-related concepts.

Data Analysis

Each writing activity used across the four-month period was analyzed first from the teacher's perspective: What were the functions that the teacher intended the writing to serve? How did the writing fit in with other activities and with classroom discourse? Two unit calendars were constructed from this analysis; each unit calendar showed the nature of writing in each lesson, the relationship of that writing to ongoing conceptual development, and the purposes of the writing as intended by the teacher. (Table 4 shows the unit calendar for the adaptations/scientific inquiry unit.)

Each student's writing was analyzed chronologically: What did the writing reveal about the student's understanding of the science concepts being studied or about the student's developing understanding of the nature of science and scientists' work? What did the writing reveal about student thinking? What purposes did the writing appear to serve for the student? Analysis charts were developed to trace student thinking revealed through the writing and to describe the purposes of the writing from the students' perspectives.

The relationship between the writing and the classroom discourse was analyzed through verbatim analyses of selected whole-group and small-group lessons. Nine lessons were selected for focus. These lessons included both whole-group and small-group interactions. The lessons were not selected randomly; rather, they were selected to represent different points in time, a variety of activity modes, and a variety of purposes for the writing tasks. In addition, they were

Table 4

Scientific Inquiry/Adaptations Unit Calendar

TOPIC/ CONCEPTS	LESSON ACTIVITIES	WRITING ACTIVITIES	TEACHER INTENTIONS FOR WRITING
9/10/90 DAY 1 Images of scientists--stereotypes	Draw a picture of a scientist at work. Discuss stereotypes of scientists.	Draw a picture of scientists at work. Write about what this scientist is doing, whether the scientist's work is important or not, what this scientist is like as a person, and whether you would like being a friend of this scientist.	To **elicit** student conceptions of scientists and their work To stimulate discussion about stereotypes
9/11/90 DAY 2 Stereotypes	Discuss stereotypes of boys and girls Create class list of our stereotypes of scientists What really makes someone a scientist? Look at photo of a scientist in a lab--is this person a scientist? Can you tell by looking? Small groups: Look at pictures of humans engaged in variety of activities. Do you think this person is a scientist? Why or why not?	Class list constructed together and written on overhead by teacher Students copy list in journals	To summarize and synthesize our ideas about stereotypes of scientists for future **contrast** with explorations of scientists at work

Table 4 (contd)

9/12/90 DAY 3 Contrast stereotypes of scientists' work with important features of scientists' work	In journals, list 3 stereotypes of scientists Review class list about stereotypes of scientists and create class list about important features of scientists' work Share and discuss pictures of humans at work: Are these people scientists? Watch video of interview with an entomologist. What important parts of scientists' work can we add to our list?	In journals, list 3 stereotypes of scientists Class lists of stereotypes of scientists and important features of scientists' work	To **elicit** student conceptions of "stereotypes" and "scientists" To enable students to **clarify** and **review** meaning of stereotype To show **contrast** between stereotypes and the central features of scientists' work To **synthesize** ideas
9/13/90 DAY 4 Scientists as more than experimenters-- as readers, writers, talkers	Watch video of interview with an entomologist again. What else does this scientist do besides experimenting? Look at print of a painting of an older woman working at her desk. Write to the person who lent us the print describing reasons you think this person is/is not a scientist and describing your reactions to the painting. Consider your audience. **NOTE:** The painting is of Nobel Prize-chemist Dorothy Mary Hodgkin	Writing a letter to person who lent us the painting: Describe whether or not the woman in the painting is a scientist and give reasons. Describe personal reactions to the painting.	To **assess** how students are understanding ideas about stereotypes. To **elicit** student conceptions about scientists and stereotypes. To enable students to **use** the ideas about stereotypes and important aspects of scientists' work to **predict** whether the woman in the painting is a scientist.

Table 4 (contd)

9/17/90 DAY 5 Contrast stereotypes vs. important aspects of scientists' work	Reflect on and add to class lists of stereotypes vs. important features of scientists' work. Tape copies of list in journals for future ref. Read some students' letters about the painting. Reflect on ways in which students used stereotypes or important features of scientists' work in writing the letters. Teacher tells class a little about Dorothy Mary Hodgkin, the woman in the painting. Teacher dresses up as stereotyped scientist. Students interview her to find out if she a scientist. Students write in journals about ways in which they are/are not like scientists.	Class list is copied and taped on inside back cover of journal for future reference. Share and reflect on students' letters about the painting. In journals write about ways in which you are/are not like a scientist.	To enable students to **reflect** on, **synthesize**, and **contrast** ideas generated by the class. To enable students to **reflect** on their writing and to assess whether they were able to use ideas about important features of scientists' work in their writing? To enable students to use the ideas about important features of scientists' work (vs. stereotypes) in thinking about their own lives.

Table 4 (contd)

9/18/90 DAY 6 Becoming scientists: Introduce problem about desert vs. Michigan species diversity	Share and reflect on journal writing about ways in which students see themselves as scientists. Introduce terms "organism" and "species." What organisms can we name at our school? Groups: List as many organisms as you can that live in Michigan. Do the same thing for the desert. Create a class chart of brainstormed lists of organisms. Discuss central problem: Are there more different species of organisms living in Michigan or in the desert?	Share and reflect on journal writing about ways in which students see themselves as scientists. Groups create charts of lists of organisms living in Michigan and in the desert by putting Groups contribute to class chart of lists of desert and Michigan organisms.	To **analyze** and **reflect** on ways in which our writing shows growth in our understanding of stereotypes vs. important features of scientists' work. To **elicit** and **record** student prior knowledge about organisms in Michigan and the desert. To help **establish a problem** to explore. To **synthesize** and **display** ideas generated by entire class for future reference.
9/19/90 Day 7 Establishing the problem: Are there more different species in Michigan or in the desert? Why?	Look at brainstormed lists of desert and Michigan organisms and discuss predictions about number of species in desert vs. Michigan. Write individual predictions and reasons in journal. Define words "adaptation," "structure" and "function." Use these ideas in exploring why there are no cacti living in the wild in MI Brainstorm ways we could do research to answer our question	Write in journals individual predictions and reasons about whether there are more different species in Michigan or on the desert.	To help **establish the problem** by having students make individual predications. To **keep a record** of individual student predictions to support students in keeping track of changes in their ideas.

Table 4 (contd)

9/20/90 DAY 8 Researching the problem: Chameleon adaptations	Review terms: adaptation, organism, structure, function. Show pictures and discuss adaptations of chameleon. Fill out research chart together as a class about adaptations of a chameleon to desert environment. Read to class about desert fish. Reflective journal writing: Write a letter to Dr. Roth telling her how things are going for you in science so far this year.	Class research chart on overhead about chameleon adaptations. Reflective journal writing: How are things going in science?	To **model** how to organize data collected about desert animals and their adaptations in a chart. To **elicit** student feelings and comfort level about participating in this scientific community.
9/24/90 DAY 9 Research on desert animal adaptations	Review and use terms: organisms, structure, function. Together as a class read about chameleons and study pictures of them. Describe ways they are adapted for desert life and write these down on individual "research charts." In groups students begin research about desert animals (library), recording data about adaptations on individual research charts. Reflective journal writing: Write about an interesting desert animal adaptation you discovered or about something you are wondering about.	Write data discovered through library research about desert animals and their adaptations on individual research charts. Reflective journal writing: Write about an interesting desert animal adaptation you discovered or about something you are wondering about	To enable student to **use** ideas about adaptations, structure, function in conducting research about desert species. To **record** data discovered by different groups through reading about the variety of desert animal species. This data is being collected to help students **construct** an answer to the central problem. To begin to **challenge** students' ideas that not very many organisms live on the desert.

Table 4 (contd)

9/25/90 DAY 10 Sharing research about desert animal adaptations	A student from each group teaches the class, using the overhead to fill in information about desert animal adaptations on the class research chart. Groups use books to look for as many different names of the desert animals as possible. These findings are added to class chart about desert species.	5 students write on overhead transparency as they teach class about the desert animal species/adaptations they discovered in their research. Students add to their individual research charts about desert animal adaptations. Groups write names of desert animals they discover from books on yellow stickies and add these to the class chart of desert species.	To enable students to **share** their research findings with class. To provide a context for students to **use** new terms (adaptation, structure, function) To help students keep a record of their findings. To **stimulate student appreciation** of diversity of desert animal species To **create conceptual conflict** about predictions about numbers of species on the desert
9/26/90 DAY 11 Research on desert plant adaptations	Quick write in journals: Use terms (adaptation, structure, function, desert, species) in a sentence in a way that shows how they are related to each other. Discuss our images of deserts as barren, with no plants, and our predictions that Michigan would have a lot more plant species than the desert. Groups do desert plant research, writing findings on research chart. 5-minute challenge: How many different plants can you find in our resource books that live on the desert? Add these to class list of desert plant species.	Quick write in journals: Use terms (adaptation, structure, function, desert, species) in a sentence in a way that shows how they are related to each other. Students write findings about desert plants and their adaptations in individual research charts. Students write names of desert plant species they discover on yellow stickies which are put on the class desert species list.	To **assess** student progress in ability to **use** these terms. To encourage students to **connect** ideas together. To keep a **record** about research findings about central problem. To **appreciate** diversity of desert plant species. To **create conceptual conflict** about predictions to central problem.

Table 4 (contd)

9/27/90 DAY 12 Sharing research: Desert plant adaptations	Students teach about their plant adaptation findings, writing findings on class overhead-transparency chart. Begin laboratory on plant adaptations (looking at different types of plants and predicting whether each plant is well adapted for desert life).	5 students write on class overhead-transparency chart as they teach the class about their findings about desert plant adaptations. Students add to their individual research charts about desert plant adaptations. Teacher models how to write about observations and predictions during plant laboratory.	To **share** research data with the class. To **organize** and **synthesize** class findings about desert plant adaptations. To **model** how to think and write about observations and predictions about plants.
9/28/90 DAY 13 Plant Lab: Desert plant adaptations	Discuss and reflect on behavior in laboratory work. Write in journals about helpful things to do in groups during laboratory work. In groups students explore a variety of plants, hypothesizing about their likely success in living in a desert environment. Students write down their predictions and reasons.	Write in journals about helpful things to do in groups during laboratory work Students write down their predictions and reasons about whether plants they are observing are well adapted for desert life.	To **reflect** of norms of behavior in this scientific community and other scientific communities. To encourage students to **predict** and **explain** why certain plants may be better adapted to desert life than others. To **gather** and **organize** data for future reference regarding the central problem.

Table 4 (contd)

10/2/90 DAY 14 Research on desert plant adaptations/Nature of scientific inquiry	Review structure, function, organism using index quiz cards with students taking turns as teacher. Read from Pringle book about functions of spines on cacti. Show book of desert flowers--over 100 kinds mentioned in the book. Student-led demonstration: Cutting open a thick leaf to see if lots of water stored inside. Discuss demonstration: Does this prove it will survive well in the desert? In journals, write down questions you're wondering about the plants you observed. How could you do an experiment to find out if these plants are well adapted to the desert or not?	In journals, write down questions you're wondering about the plants you observed. How could you do an experiment to find out if these plants are well adapted to the desert or not?	To encourage students to construct questions and experiment plans that could address those questions.

Table 4 (contd)

10/3/90 DAY 15	Students propose ideas of experiments that could test out our predictions about which plants are best adapted to the desert. Teacher scaffolds students' efforts in critiquing these experiment proposals. Students revisit central problem: Have you changed your prediction? Students watch video of Namib desert, keeping track of new organisms mentioned and keeping track of desert scientists and important features of their work.	Students keep a list of organisms mentioned in video about Namib desert On board, teacher keeps list of desert scientists and their work.	To **gather** and keep a **record** of data that will help answer the central problem. To **appreciate** the variety of organisms adapted for desert life. To help students **reflect** on ways these scientists' work is different from their stereotype of scientists.
10/4/90 DAY 16 Research on Namib Desert organisms and scientists	Students explain to visitor what we have been exploring in our science class. Reflect on desert organisms and scientists that have appeared so far in the Namib Desert video Watch next portion of Namib Desert video, keeping a list of organisms and scientists.	Students keep a list of organisms mentioned in video about Namib desert On board, teacher keeps list of desert scientists and their work.	To **gather** and keep a **record** of data that will help answer the central problem. To **appreciate** the variety of organisms adapted for desert life. To help students **reflect** on ways these scientists' work is different from their stereotype of scientists.

Table 4 (contd)

10/8/90 DAY 17 Research on Namib Desert organisms and scientists	Fast write in journals--what adaptations means to you and/or questions you have. Keep writing continually until time called. Create class concept map about adaptations. Finish Namib Desert video, keeping lists of organisms and scientists. Journals: What would it be like to be a desert scientist like Mary Seeley?	Quick write in journals--what adaptations means to you and/or questions you have. Keep writing continually until time called. Class concept map written on board. Students keep a list of organisms mentioned in video about Namib desert On board, teacher keeps list of desert scientists and their work. Journals: What would it be like to be a desert scientist like Mary Seeley?	To assess and have students **reflect** on how they are making sense of "adaptations." To construct and model a representational tool for organizing ideas. To **gather** and keep a **record** of data that will help answer the central problem. To **appreciate** the variety of organisms adapted for desert life. To help students **reflect** on ways these scientists' work is different from their stereotype of scientists To encourage students to **reflect** on the nature of scientific inquiry and to **appreciate** scientists as humans

Table 4 (contd)

10/9/90 Day 18 Synthesis of findings: Concept mapping	In journals students respond to individual teacher comments, questions. Revisit painting of Dorothy Mary Hodgkin, the chemist: How is she similar/different from Mary Seeley, the desert scientist? In groups, create word pictures (concept maps) using terms we have been studying. Put the words together in a way that makes sense and then explain your word picture to a teacher.	In journals students respond to individual teacher comments, questions. In creating concept maps in groups, students write the key words and terms on yellow stickies. Then they arrange the stickies in a word picture.	To encourage students to **reflect** on their learning and experiences in science class. To **reflect** on and use new concepts in a way that supports **synthesizing** of information. To see that all these ideas--about adaptations and about scientific inquiry--are connected in significant ways.
10/10/90 DAY 19	Students take written test. Students are interviewed about #1 on the test (a unit concept map students create)	Students take written test, which includes a unit concept-mapping task and questions that challenge students to use concepts in new situations and to reflect on changes in their learning.	To assess and enable students to **reflect** on their learning and growth in understanding. To provide contexts for students to use and connect concepts they have been using.
10/11/90 DAY 20 Synthesis and reflection activities	Finish and review tests. Create class list: Stereotypes vs. the real thing Create class project to share our findings with others. Begin work on project.	Students complete written tests. Create class list: Stereotypes vs. the real thing Students create maps of world deserts and pictures of a variety of kinds of scientists for school bulletin board project they suggested.	

lessons of reasonable technical quality so that verbatim transcripts could be made. The lessons were analyzed in terms of the learning qualities of a learning community described earlier (see Table 1). For example, the lessons were used to identify examples and counterexamples of students' showing respect for each others' ideas or to identify frequency and quality of student-generated questions. The lessons were also used to analyze the relationship between students' writing and their talk during large and small-group discussions. How did the teacher's purposes for writing and for class talk compare/contrast? How did the students' purposes for writing and for class talk compare/contrast? Did the students' writing play a role in their contributions in class discussions? How did the class discussions and small-group interactions influence students' writing?

To illuminate some critical features of learning-centered writing, I also analyzed a set of writing activities that contrasted with those used in this fifth-grade classroom. Using an analysis framework identical to one used in this study, I analyzed a set of writing activities I used with my seventh graders in 1975-76. This analysis helped to compare writing that is work-centered with writing that is more learning-centered. The discussion of findings begins with this analysis.

Prelude to the Study: The Role of Writing in Work-Centered Science Classrooms

I will draw from my past science teaching experience to illustrate examples of work-centered writing. Keep in mind as you look at these examples that I was not an uncaring teacher. I wanted my students to understand and enjoy science. I worked hard, I respected kids, and I took an interest in them. But I did not have a conceptual change lens to use in looking at their learning; I was locked in a work- and product-oriented mode.

As I looked through a notebook summary of my teaching in a seventh-grade classroom during 1975-76, I was surprised to find that all student writing was graded and figured in as a percentage of the report card grade. Writing activities took the following forms:

Laboratory reports
Tests and quizzes
-Fill-in-the-blank review sheets
-Review sheets for tests and exams

Crossword puzzles
Occasional short reports

The laboratory reports were kept in a science-lab notebook and were written in the same form each time (see Table 5). The analysis section was always the most important part of the report and figured most into the grade for the lab report.

The text usually posed about three questions for the students to answer in their analysis of the laboratory activity. These were called "Interpretation Questions" and they were not easy, fact-oriented questions. They required thinking. How I wish I had been a researcher back then and had saved some of the students' notebooks so I could share samples of the students' actual writing! I remember emphasizing to students at the beginning of the year that they must write down the procedures neatly and completely. They were expected to read the experiment and write out the purpose and procedures before coming to class to do the experiment. After the experiment I expected to see neatly written and accurate observations. When they looked under the microscope, for example they needed to draw what they were supposed to see to get a good grade. If they drew what they really saw, I would have taken off points, I'm sure! What I remember in grading the analysis section was how frustrating it was that students had such difficulty getting it "right." While I communicated to them that there was no one right way to answer the question, there definitely was one right answer I had in my mind.

Table 6, for example, is a worksheet I left for students to complete when I was attending a conference. Notice the language: "Here are the correct answers to Investigation 2.5. Check and correct your answers." Then, buried in the text at the end of the answers: "Your answers do not have to be exactly the same as long as they give the same idea." Clearly, there was one right answer, although students were given leeway to put that answer in their own words. And what happened when the students' answers did not match mine? If it occurred with a few students (I hate to think how many it had to be before it bothered me!), they just got poor grades on that lab, and we moved on to a new lab activity. Obviously, if a lot (most?) of the students missed the point, we talked about it in class--but probably that was it: "You guys had trouble with this. What would have been a better answer?" And then it would have been on to the next laboratory.

Table 5

Format for Writing Laboratory Reports, 1975-76

USING THE MICROSCOPE

When you do Science experiments, you will usually be asked to write up a Laboratory report. During today's lab, we will be learning how to use the microscope and how to write up a Lab report. All lab reports will have these sections: Title

I. Purpose
II. Materials
III. Procedures
IV. Observations
V. Analysis

The title of today's lab is already on the paper for you. You fill out the rest of the form:

I. Purpose:

II. Materials:

III. Procedures: 1. We will draw a diagram of our microscope and label its parts.
2. We will learn how to use the microscope by looking at the objects our group brought in.
3. We will make large, labelled drawings of at least 3 of the objects we looked at.
4. We will write down in our Analysis:
   a) How to prepare a wet mount slide
   b) Summarize ~~5 of the~~ most important things to remember when using the microscope.

IV. Observations:
A. Diagram of microscope:
B. Drawings of objects:
a) b)
c)

V. Analysis:
A. How to prepare a wet mount slide:
B. 4 important rules in using the microscope:

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Table 6

Science Classwork, November 1975

SCIENCE CLASSWORK WED., NOV. 18, 1975

I. Here are the correct answers to Investigation 2.5. Check and correct your answers.

A. (2 points) The leaf is basically green, but there is white along the very edges of the leaf and a circle of red toward the center of the leaf.

B. (2 points) The starch is located throughout the whole leaf except in the veins and at the very edges of the leaf. The distribution of the starch is very similar to the distribution of green in the leaf.

2 points 1. The areas of the leaf that show the presence of starch are the same as the green areas of the leaf. Therefore, chlorophyll seems to be necessary for the production of starch.

4 points 2. green plants + carbon dioxide + light + chlorophyll ^^^

The quizzes and tests were comprehensive and similarly focused on right answers. I purposely gave many fill-in-the-blank questions instead of essay tests to give students a better chance of doing well. An interesting aspect of the photosynthesis quiz in Table 7 is the clear demarcation between strictly photosynthesis questions (1, 2, 3, 4, 8) and the questions that related to the introductory information in the text about the nature of science and scientific inquiry (questions 5, 6, and 8). All of these questions are posed in ways that cajole students into displaying knowledge of vocabulary words (chlorophyll, photosynthesis, hypothesis, pigments, theory). Notice that spelling counts, too! Students must display their knowledge of the correct words in the correct form. Unit tests generally did more to probe for understanding but still placed primary emphasis on questions with correct factual answers.

On the photosynthesis test, for example (see Table 8), the first question is one students had been told over and over again would be on the test: "Write the complete equation for photosynthesis." Notice that students are given clues about how many words are in the correct equation. Questions 3 and 4 break the pattern of fact-oriented, expected questions. These were ideas we had not discussed in class; they required students to draw from what they had learned. It is fascinating to me that I asked these two questions long before I consciously thought about students having beliefs that plants get food from the soil. What is equally fascinating to me today is that I did not weight those questions heavily in grading, because hardly anyone got them "right"! I do not remember reading interesting ideas that students put down, just lots of "wrong" answers.

The second page of the test is full of fill-in-the-blank questions. I thought they were tougher and better indicants of understanding than matching and true/false. But look what students actually had to understand to give the correct answer. On # 8, for example, students did not need to understand that only green plants can make their own food, a central idea in biology. They only needed to know that green plants contain chlorophyll, and the question gave at least two hints about what word would be the correct answer. And what does #10 show about students' understanding of the chemistry of photosynthesis? Given that we (I mostly) had gone over this explanation over and over again in class, it did not require much thinking or understanding to get

most of this answer correct. If they paid attention at all, they would have heard over and over again the phrase "split the water molecule," and now all they had to do was write down the key word "split."

Who saw the students' notebooks of laboratory reports? Who saw their tests or their worksheets? I was the only person who ever read their lab reports. I read them carefully, graded them, and I am sure I wrote comments next to places where the answers were wrong or wrote words of encouragement when they did a particularly good job. But that was the end of that piece of writing. The students looked back at the lab long enough to see a grade and, I hope, to read the comments. Other than that, that writing was finished. Writing was not revisited or revised, and it was a private experience shared only with the teacher.

I intended these kinds of writing activities to be supportive of student understanding. A stated goal I had was to help my students learn to think like scientists. But what was I communicating about how scientists think from these kinds of writing activities? I was certainly communicating that scientists think clearly and get the one right answer on the first try. I was also communicating the following:

- Scientists share equipment but not ideas
- Knowledge of specialized vocabulary and facts is what is most important to learn from experimental work
- Science experimentation is fun and social in the doing part but frustrating and private in the writing and ideas part
- Scientific understanding comes quickly or not at all
- Scientists write things down in order to show off what they have learned, and their products must be scientifically and grammatically correct in order to count
- There is one right way to interpret every experiment, every observation, every question
- Science is mysterious--you have to figure out the one right answer and also come up with a way of making it sound like your own idea by putting someone else's idea into your own words

I think students enjoyed science class and left with a positive attitude toward learning science because I was enthusiastic, had lots of activities to do, cared about students as people, had

Table 8

Photosynthesis Test, December 1975

SCIENCE TEST #2

PHOTOSYNTHESIS DEC. 2-3, 1975

1. Write the complete equation for photosynthesis:

_____ + _____ + _____

_____ + _____ + Produces----->>

_____ + _____ + _____

2. Fill in the chart:

Man Depends on Plants For:	Plants Depend on Environment for these raw materials:	How plants get the raw materials to the leaf:
1		
2		
3		

3. In early Greece, the scholar Aristotle said that plants received all their food directly from the soil. Criticize his hypothesis based on what you know about photosynthesis.

4. VanHelmont planted a 5-lb. tree in 200 lbs. of soil. After 5 years the tree weighed 164 lbs. The soil still weighed almost 200 lbs. All he ever added was H_2O. Which of the following are reasonable interpretations of his results? (Choose one or more)

_____a. The soil does not supply food to the plant.

_____b. The soil does supply food to the plant.

_____c. Water must somehow help the plant gain weight.

_____d. Green plants might absorb food from the air.

5. Joseph Priestly did the following experiments: (See page 2)

What did he show:

6. $C_6H_{12}O_6$ is a sugar and is also a carbohydrate. All carbohydrates contain three elements - _____, _____ and _____.

7. All living things need food as a source of _____.

8. Only green plants can make their own food, because they are the only things that contain _____ which can absorb and use energy from the sun.

9. TWO molecules of CO_2 contain _____ atoms of _____ and _____ atoms of _____.

10. Fill in the blanks to tell about the chemistry of photosynthesis:

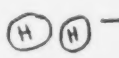
----> the energy is absorbed by -----> the energy is used to

a. _____ energy

b. _____ in the leaf.

c. _____ a water molecule

What happens to the Hydrogen?



d. _____

_____

Where does the Oxygen go?

e. _____

11. Which of the following cells would be capable of carrying on photosynthesis?

____maple leaf cells in summer

____bark cells of a tree

____Euglena (Euglena is a one-celled organism with chloroplasts and a flagella)

____human blood cells

____cells in a blade of grass

____muscle cells of a dog

____maple leaf cells in fall

ow/3hr-36

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plants and animals in the room, and figured out ways to help students succeed in getting good grades in science if they would try. Unfortunately, I do not think very many students enjoyed science because it helped them make richer sense of the world around them or because of the satisfaction they enjoyed in coming to understand natural phenomena in new and more powerful ways.

The Role of Writing in a Conceptual Change-Oriented Classroom

The kinds of writing I had students do this year and the purposes for that writing stand in contrast with the work-oriented, product-focused kinds of writing I had students do in the past. To illustrate these differences, I will first describe several writing tasks that I posed for students this year and how these writing tasks fit into the overall science curriculum. Using examples of students' responses to these writing tasks across the fall, I will trace the ways in which the writing fostered development of connected and useful understandings of science concepts as well as the disposition to be reflective about the nature of science. Tracing the writing as it was used by the students across time will reveal the multiple purposes of writing in a conceptual change classroom, the ways in which I made decisions about the writing activities, and the ways that the writing activities contributed to the development of a learning-centered community.

Curriculum Threads

The science curriculum across the fall consisted of three major threads, or units, that were gradually woven together. Figure 3 shows how the year began with an emphasis on the nature of science and scientific work. Students were challenged to reconsider stereotypes of what it means to do science. This nature-of-science thread continued to be a central curricular strand throughout units on adaptations and food for plants. The adaptations unit focused on a central problem: Are there more different kinds (species) of plants and animals in the desert or in Michigan? Students studied plant and animal structures and their functions and observed a variety of plants to figure out ways they are adapted or not adapted for desert life. They consulted books and videotapes to learn about the diversity of life that is adapted to live in the desert. In the end, students did not have a definitive answer to the central problem, but they had begun to question their prediction that there

are definitely more plant and animal species in Michigan. The next unit explored how plants get their food. Woven into lessons about photosynthesis were pieces of the other two strands. Students reflected on ways in which they were/were not acting like scientists in their efforts to answer the question: What is food for plants? The class also revisited desert plant adaptations for getting and conserving water: How does photosynthesis help us understand why plants need water, anyway?

To illustrate how writing activities developed in this classroom, four writing activities from the nature-of-science strand will be described and analyzed from the teacher and the students' perspectives. A listing of all the writing activities included in this strand in Table 4 shows how these sample writing activities fit into a larger set of instructional activities. Comparisons of the two columns, daily Lesson Activities and Writing Activities, shows how the writing activities were almost always part of some other kind of activity--an experiment, a class discussion, role playing, watching videotapes or other visuals. It also shows that students wrote during almost every science lesson, that writing about the same concepts took place over a relatively long period of time, and that writing about the nature of science was woven into the unit on desert adaptations.

The fourth column, teacher intentions for the writing activities, shows the multiple purposes that writing served across time. Boldface words in this column were used to emphasize how the teacher intentions often reflected aspects of the features of scientific understanding (connectedness, usefulness, disposition to reflect) and of a conceptual change instructional model (establish a problem, elicit children's ideas, challenge their naive conceptions, contrast students' conceptions with scientific explanations, provide opportunities for students to use concepts to explain new situations) described earlier as the frameworks being used to guide instructional decision making. Reading down this list of highlighted words reveals an important aspect of the conceptual change framework that is not obvious in the way the framework was described above. Although the conceptual change model articulated in Table 3 and Figure 2 suggests a specific order of goals and activities (elicit, challenge, contrast, use), this list of activities and the teacher's intentions shows that the model was used in a recursive way. Student conceptions continued to be

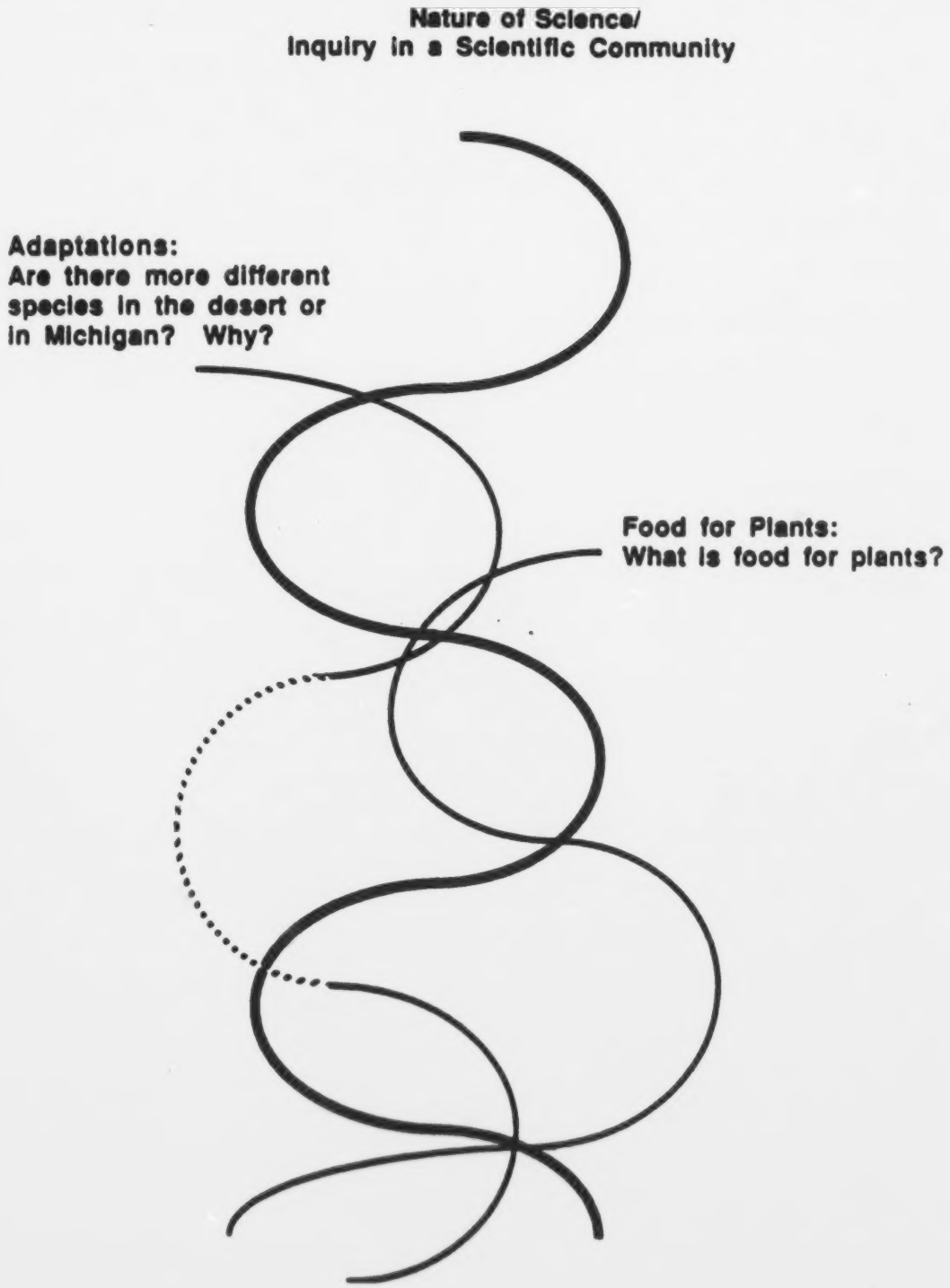
Nature of Science/
Inquiry in a Scientific Community
Adaptations:
Are there more different species in the desert or in Michigan? Why?
Food for Plants:
What is food for plants?

Figure 3. Curriculum strands, Fall 1990.

elicited throughout the unit, and students' ideas were often challenged after they had already been contrasted with a scientific explanation. Reflection about ways in which we were being scientists and reflection by each individual student about his/her changing ideas about scientists, adaptations, and food for plants took place throughout the fall. It was not something that occurred only at the end of each unit.

Writing Activities in the Nature of Science Strand

The four sample writing activities were selected to represent different purposes writing served. The first writing activity asked the students on the first day of science to start their science journal by drawing a picture of a scientist at work and by describing this scientist: What is your scientist doing? Do you think this scientist's work is important? Why or why not? What is this scientist like as a person? Do you think you would like this scientist as a friend? Tell why or why not. As indicated in Table 9, the primary intention of this writing was to elicit students' conceptions and stereotypes of scientists for later contrast with examples of real-world scientists. Figure 4 shows six students' drawings of scientists, and the students' descriptions of the scientists are included in Table 9. (Note: The students' own spelling is used in this figure; words in parentheses were added to help the reader translate the students' spelling when it was a difficult translation. In addition, different print is used to highlight the teacher's response to students' ideas in their journals).

Although the writing of all 22 students was analyzed, 6 students' writings were selected for focus in this paper. It was difficult to select these students, since each student's writing tells an interesting and unique story. The students here were selected because they show a range of responses among students who in traditional classrooms would be labelled average or below average. Two of the students, Nan and Justin, regularly missed portions of science class for speech therapy. In addition, Nan had serious reading and writing difficulties. Laticia was not only a new student to our class in October, she was moving from a mostly black school to a classroom in which she was the only black student. She struggled to be accepted, and her assertiveness was often met with rebuffs. Russell missed a week of school early in the fall to attend a retreat for

students needing emotional support and confidence-building. John was an active boy who loved football but has a difficult time concentrating on school work. Nathan was an extremely quiet boy who could easily become invisible in a classroom.

The six students' responses to the four sample writing activities are presented in Figure 4 and Tables 10-13. The analysis beneath each student response describes the purposes the writing served for individual learners. The intended teacher purpose for a writing assignment did not always match the purposes that the writing activity served for the individual. This emphasizes how conceptual change is not a neat, orderly, predictable process; it develops in different ways for different learners. The variety of responses among just these six students illustrates one of the challenges of this kind of teaching. The teacher must be ready to recognize and respond to different students in different ways. This, again, is an important feature of the conceptual change model as it was used in this classroom, but it is not captured in the model as depicted in Table 3.

The first writing activity: Drawing and describing a scientist. What purposes did the writing seem to serve for these six students? On the first written assignment, the students' drawings of the scientists all looked pretty similar (see Figure 4). As anticipated, most students held images of scientists as working with chemicals in a laboratory. I was surprised that a number of students thought about scientists as digging for dinosaurs, but I was not surprised that all 22 students drew male scientists.

The students' written descriptions of their scientists (Table 9) provided much richer information about their thinking about science and scientists. Nan, for example, revealed strong negative feelings about science in her response: "I do not liek scienc and I do not like scientist." Nan is a student with speech and reading difficulties who is often pulled out of class for resource-room help. She does not usually experience a lot of academic success. In contrast with Nan, Nathan's response revealed positive feelings about fossil science: "I like dinosasours and I like there bones." John, Justin, and Russell all revealed conceptions of a "mad" scientist. Russell, a student dealing with difficult emotional problems at home, seemed to enjoy the weirdness of his scientist: "He is a Mad scientist I would like to be friends. This scietist is sleeping all day and

Table 9

Teacher Intentions and Student Responses to Writing Activity 1

Writing Activity	Teacher Intentions
Draw a picture in your journal of a scientist at work. Then tell: 1. What is your scientist doing? 2. Do you think this scientist's work is important? Why or why not? 3. What is this scientist like as a person? Do you think you would like this scientist as a friend? Tell why or why not.	Elicit student conceptions of a scientist For later use in contrasting stereotypes of scientists with real-world scientists

Nan	Nathan
1. This scientist is making a lickwind. I think this scientist work in important because. I think it is important but I cannot think why. I think not like to be friends with this scientist because I do not liek scienc and I do not like scientist. Nan - Super job with your journal! I am also very pleased with your participation in discussions. I'm wondering why you say you don't like science? Mrs Roth Elicits negative feelings about science and scientists; scientists as male	1. Getting the scull out of a rock 2. Yes because we won't have dinosaur bone without him 3. yes because I like dinosasours and I like there bones Nathan - Your are doing a good job in your journal! I liked it when you raised your hand today - you have good ideas to share with the class! Mrs. Roth Elicits his interest in dinosaurs and fossils; positive feelings about science
Laticia	**Russell**
Not a member of our class yet.	-Trying to make a special formula -yes, because they invent things -He likes to work with his cat. He is a Mad scientist I would like to be friends. This scietist is sleeping all day and works a night Russell, Excellent work in your journal. I also like the way you have so many interesting things to say in class. Mrs. Roth Elicits conception of scientist as mad, weird, odd (sleeps in day), as inventor
John	**Justin**
Did not write answers to questions; only did drawing Elicits conceptions of a "mad" scientist. (Did not answer questions so little information available about his feelings about science).	1. This scientest is mixing poison gases, 2. yes. he mixes cemicals for mediscen 3. no. because he is mad. Justin, Terrific work so far in your journal. I also think you are doing a super job of listening and talking in class. Mrs. Roth Elicits conception of mad scientist in a laboratory.

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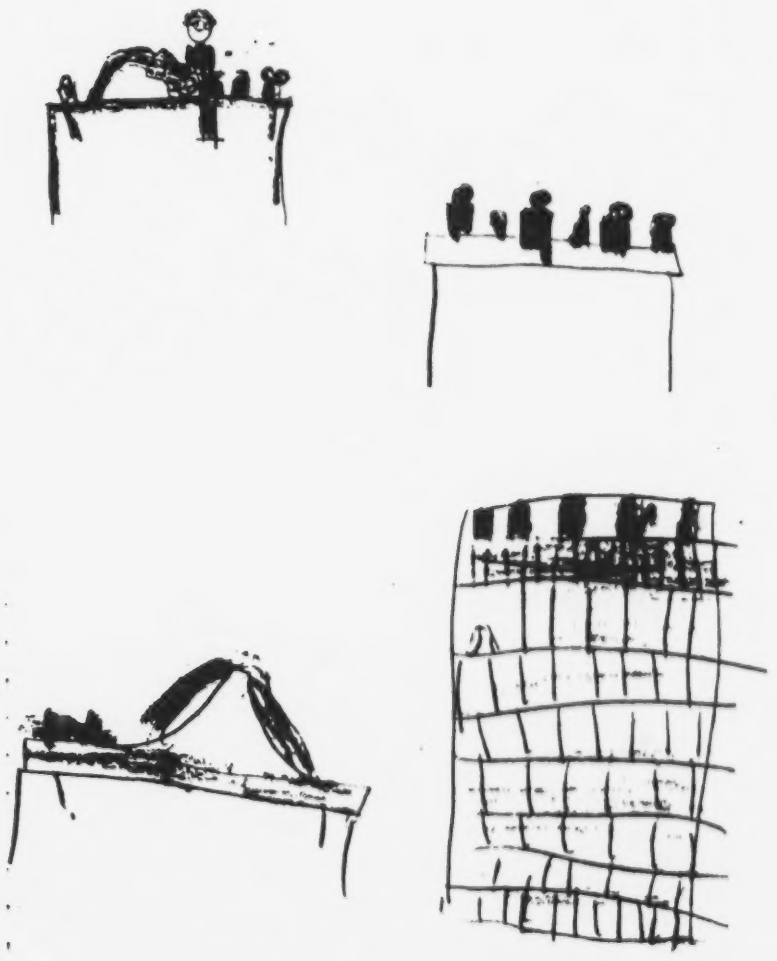
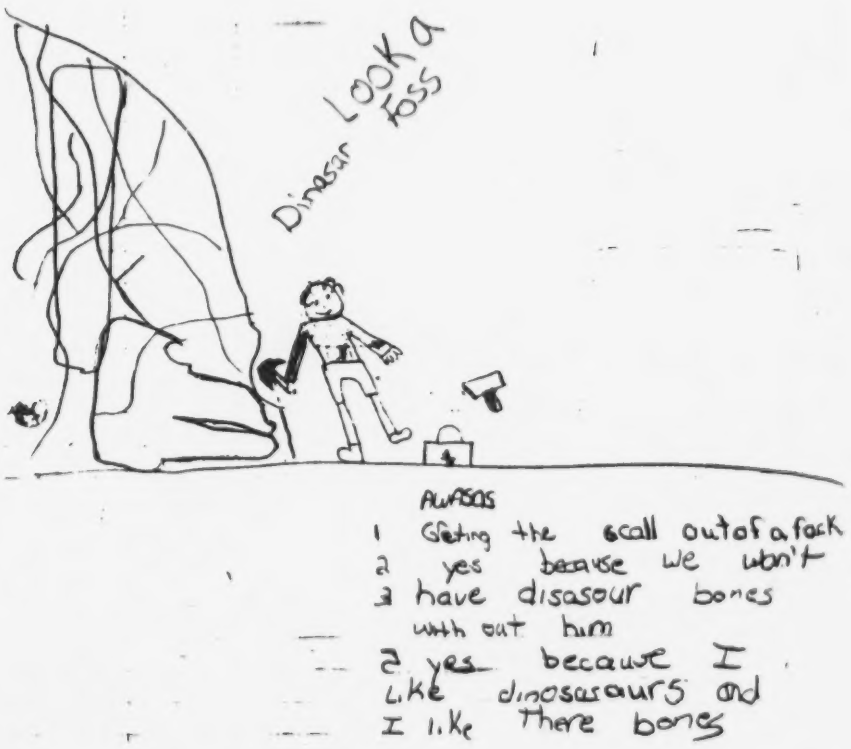


Nan


Dinosar LOOK a foss
AWSOS
1 Geting the scall out of a fack
2 yes because we won't
3 have disasour bones
with out hurn
2 yes because I
Like dinosaurs and
I like there bones

Nathan

Figure 4. Student drawings for writing activity 1.

Julia

Russell

Figure 4 (contd).

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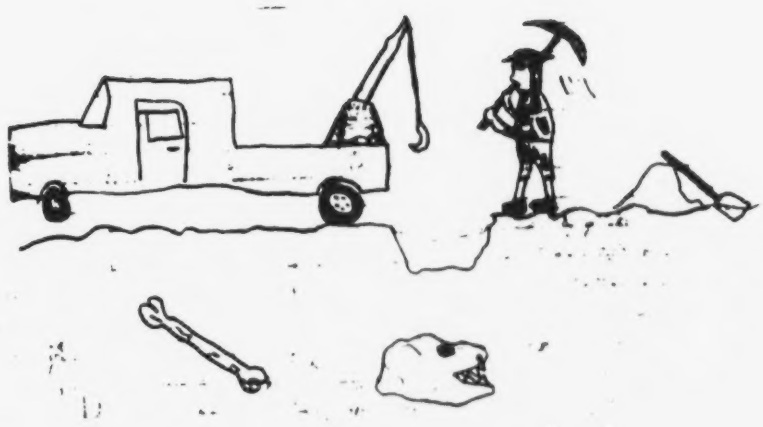
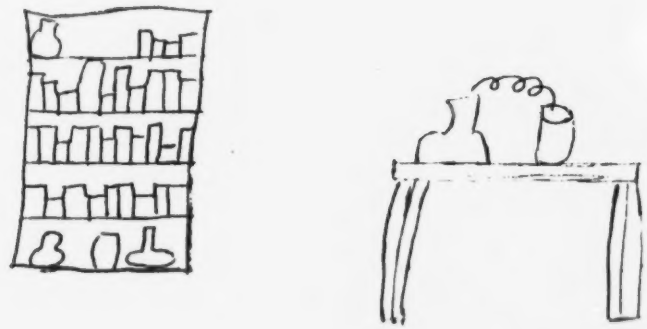
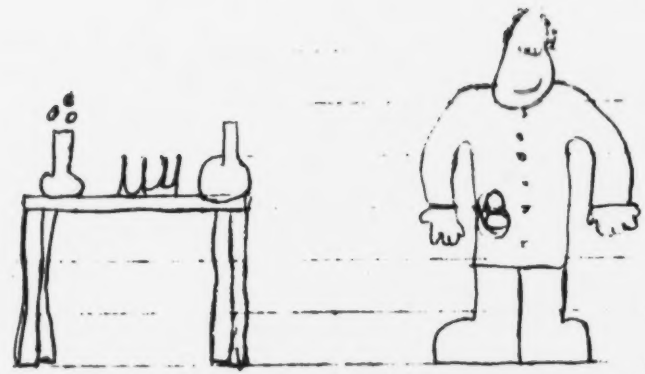


Matt





Tiffany

Figure 4 (contd).

works a night." Justin, a very verbal student who often missed portions of science class for speech therapy, communicates mixed feelings about his scientist: "Yes [he's important, because] he mixes cemicals for mediscen," but Justin would not like to be friends with this scientist "because he is mad." Looking across these five students, this first writing assignment served the intended purpose--to elicit students' conceptions of science and scientists. However, it elicited many unexpected conceptions about students' feelings about science and scientists.

The written teacher responses to these journal entries also serve an important purpose; they are not intended to challenge the students' ideas about their drawings of the scientists. However, they are intended to challenge students' conceptions of what it means to be a scientist in this classroom. They are challenging students' conceptions not in a direct, combative way that people may associate with the word "challenging." Instead, students are given messages encouraging them to act in certain ways as scientists in this classroom: "I am also very pleased with your participation in discussions!" "I liked it when you raised your hand today--you have good ideas to share with the class!" "You are doing a super job of listening and talking in class." In addition, these teacher responses also "challenged" students' conceptions of being a scientist in this class by modeling a valuing of each student's ideas. For example, Nan's dislike of science was not ignored or used against her in some way: "I'm wondering why you say you don't like science?" Nan later responded verbally to me that she didn't like science because she wasn't good in science. The response to Russell and Nathan also reflected a valuing of their ideas: "You have so many interesting things to say in class" and "You have good ideas to share with the class!"

The second writing activity: Is this woman a scientist? The second sample writing assignment (see Table 10) was intended to serve a different purpose. In this task, students were asked to look at a painting of a woman at work at her desk. The gray-haired woman has many papers around her, and she is writing with one of her hands but actually has four hands shown in motion. There is a molecular model of some sort in front of her. The painting is of Dorothy Hodgkin, a Nobel Prize winner for her studies of the structure of crystals. However, the students were not given this information. They were asked to think about whether this woman was or was

not a scientist. The writing was to take the form of a letter to the professor who had lent us a print of the painting. This assignment was given after several science lessons that focused on contrasting stereotypes of scientists with the important characteristics of scientists and their work (emphasizing through a videotaped interview with a scientist how much reading, writing, and talking scientists do). As the teacher, I hoped that this writing activity would be a first opportunity for students to try to use what they had learned about stereotypes of scientists and about the variety of kinds of work that real scientists do (including writing).

Some students, however, were not yet ready to use these new ideas. For Nan, this task served instead to elicit a new stereotype of scientists--that old women are not scientists: "I do not thik she is a scientist becous she is a old woman most old woman are not scientist." John, Justin, and Russell also did not use the new ideas we had talked about in interpreting this painting. Russell thinks she is an artist; interestingly, he describes her as weird yet does not connect that with his image of scientists as weird. Justin thinks she is a scientist but used the model as his evidence without mentioning anything about what she might be writing or reading. John thinks she is doing her taxes; she may be a scientist but she is not doing science right now. Many other students shared this idea that she can't be doing science in what appears to be a home setting. Nathan, in contrast with these students, did try to use some of the ideas about scientists that we had been discussing. He used evidence about her reading and writing to support his conclusion that she is a scientist. He also described her as looking like she is discovering something. The students' writing in this activity served important purposes for me as the teacher in making decisions about future directions of the unit. I learned more information about their stereotypes of scientists and I learned that they would need more opportunities to use the new ideas about scientists we had been emphasizing.

The third writing activity: Would you like to be a scientist like Mary Seeley? The third writing activity (see Table 11) highlighted in this analysis revealed a similar range of purposes of the writing from the students' perspectives. We had watched a videotape about life in the Namib Desert in Africa. The video showed life in the desert from the perspective of scientists working

Table 10

Teacher Intentions and Student Responses to Writing Activity 2

Writing Activity

Look at the painting Dr. Thompson lent us. Write a letter to Dr. Thompson telling him whether you think this woman is a scientist or not. Give reasons. (Journals)

Teacher Intentions

Opportunity for students to use new ideas about scientists/stereotypes to predict whether woman is scientist or not.

Nan

Dear Dr. Thompson, Thank you for the nice painting it is a good painting. I do not thik she is a scientist becous she is a old woman most old woman are not scientist. but I do like the painting. I wont to aks some thing. are you a scientist yes or no

From Nan

Elicits conception that old women are not scientists.

Nathan

Dear Dr. Thompson,

Thak you for leting Dr. Roth barrow the pantin to show use. I thought it was intresting. I thank the lady in the picther is a scientist because it look like she look at a but or something. Aewso, I thank the lady is a scientist because the book in the back ground might be recirtch book. Alwso, it look like shes taking note on a pice of paper. It alwso look like she decivering.

Sincerely, Nathan

Using ideas about many aspects of scientific work including reading, writing, research, discovering.

Laticia

Not a member of our class yet.

Russell

Dear Doctor Thompson Thank you for letting Mrs. Roth bring the picture in. I don't think that the picture is a scientist because she looks like she is an artist because she has pictures on the table and the red and black dots. The artis was probly drawing another artist. something weird abut the picture is that she has four hands, fingers look weird, has crazy hair. I don't think that she is a scients because she doesn't look like she's doing what a scientist would do. Sincerely, Russell

No evidence of using ideas about scientists as writing, studying.

Stereotype not yet challenged?

John

Dear Dr. Thompson. Thank you for letting us look at the painting it was neat. I don't think that she is a scientist because it looks like she's doing her taxes but she could be a scientist doing researce. She probly is a scientist doing her taxes. Sincerely, John

Did not use ideas about scientists writing and reading to explain the pictures.

Elicits conception that scientists don't work on science in a "home" setting.

Justin

Dear Dr. Thompson, Thank you for letting us use your neat picture. I think she is a scientist with making molicules. she is trying to do things with how things are made

Justin, Great start! Please finish your letter today. Mrs. Roth

No evidence of using ideas about scientists we had discussed; stereotype not yet challenged?

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Table 11

Teacher Intentions and Student Responses to Writing Activity 3

Writing Activity

Would you like to be a scientist like Dr. Mary Seeley (in the video we watched) and work on the desert? Why or why not? (journals)

Teacher Intention

Challenge students' conceptions of scientists' work.

Contrast Dr. Seeley's work on the desert with students' stereotypes of scientists.

Nan

I wond not like to live on the derst be cons it is to hot in the dersrt and I do not whont to git a sun born

I wonder if Mary Seeley has ways to protect herself from the sun What did you think of Mary Seeley? Is she an interesting person to you? Dr. Roth

I think see wond put a cap on a cap is to blok the sun to make a sun born on her hand. See maint put on sun plases to blok the sun from her ease. I dot now if see was inrater. But I do think that see is nice becous see dos not keep the bugs.

Negative feelings about scientists challenged. With probing, Nan describes the scientist as "nice" for releasing the bugs after she studies them.
Elicits information about source of negative feelings about scientists (they are mean and kill things?)

Nathan

no I won't like to be a sniestist and live in the desit because it would be hard to get food and water and you would die if it was really hot out.

Why do you think Mary Seeley likes working on the desert? Mrs Roth

yes because its fun colting bugs

Elicits a conception of desert life as unpleasant.

Teacher response challenges his stereotype of life on desert as a scientist.

Laticia

I wouldn't like living in a desert. Because spiders and all kinds of animals and insets could crawl on you when your sleep. Or it could get in your food. They could bite you.

I wonder if the scientists' building has good screens to keep out the insects.

I don't know they probaly do!

Elicits negative feelings about insects.

Teacher response challenges whether dislike of insects has to prevent scientific work.

Russell

I don't think I would like it becasue there woldn't be much to do and about the only thing out there is animals and sand

Would the animals be interesting to you?

No evidence that this desert scientist intrigued him.

Elicits his view that perhaps this scientist is boring in contrast with his mad scientist?

John

I think it would be hard to live in the desert because there is'nt vary much rain

Can you describe an organism that is adapted for life on the desert? Describe how it is adapted! Mrs. Roth

Elicits conception of desert life as unpleasant.

Justin

I think it would be very neat. because you could see the animals.

Which animals would you like to see on the desert? What would you want to find out about them? Mrs. Roth

Elicits his interest in animals and positive feeling about this kind of scientist ("very neat").

Stereotype of scientist challenged?

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there: Dr. Mary Seeley was featured as the head of the laboratory on the desert. I thought the way she was portrayed in the video highlighted ways in which her work contrasts with many of the students' stereotypes of scientists (including the idea that scientists are males).

I asked the students to write in their journals about whether or not they would like to be a scientist like Dr. Mary Seeley. My purpose for this assignment was to challenge students' conceptions of scientists as mad, as male, as always working in a laboratory, as isolated from other people, and so forth. I thought, for example, that the students would be excited and fascinated with the part of her work that involved driving around the desert collecting and releasing organisms for study. One of the scientists in this research station rode around the desert on a three-wheeler, jumping off to catch lizards. That seemed to make a big impression on the students. I expected them to respond favorably to being this kind of a scientist.

For Nan, however, the activity did not appear to challenge her negative conception of science and scientists: She writes about her negative view of desert life as being too hot. But with encouragement from my response ("What did you think of Mary Seeley? Is she an interesting person to you?"), Nan wrote that she did not know if Dr. Seeley was interesting, but "I do think that see is nice becous see dos not keep the bugs." Nan is referring to Dr. Seeley's release back into the desert of insects she had collected and marked. It is interesting to note that it was the actual writing part of this assignment that was critical in its success in challenging Nan's negative conceptions of scientists. If Nan had not written her ideas down, it is unlikely that I could have made this individual kind of a response that pushed Nan to think again about this scientist. Thus, while writing was just one piece of a bigger activity (watching the video and discussing it), the writing was a critical aspect of the overall activity.

The activity also seemed to challenge Justin's negative conception of the mad scientist; he thinks it would be "very neat" to be this kind of scientist. But his response also elicits more information about his conceptions, revealing his interest in animals. My written response picks up on this interest and tries to use it to challenge him to think about ways a scientist would find animals interesting: "Which animals would you like to see on the desert? What would you want to

find out about them?" Again, the writing was critical in eliciting Justin's interest in animals and provided an opportunity to help him link our analyses of scientists' work to his personal interest.

For many students, this writing activity failed to challenge their stereotypes about scientists because it instead elicited their stereotypes about desert life. (A key concept we were working on in the "Adaptations" curriculum thread was the diversity of life even in places that seem unsuitable for life, like the desert.) For example, Nathan focused on how hard it would be "to get food and water and you would die if it was really hot out." My response challenges both his conception of scientists and his conception of the desert: "Why do you think Mary Seeley likes working on the desert?" In response, Nathan concedes that "its fun colting [collecting] bugs." However, bugs bothered Laticia! She rejected life as a desert scientist because of all the bugs and insects crawling on you during your sleep. Again, my response encouraged her to reconsider life as a desert scientist: "I wonder if the scientists' building has good screens to keep out the insects."

In retrospect, it does not seem surprising that this writing task elicited students' negative reactions to desert life. An important point, however, is that as a teacher I thought this desert scientist would be appealing to the students and that she would challenge their conceptions of scientists at work. This writing activity helped me appreciate the range of student responses and to think about ways to help students connect Mary Seeley with the ideas we had been talking about the nature of science and scientific work. Mary Seeley, like "the lady with four arms" (Dorothy Hodgkin) became a name that the students could recognize, because in the ensuing lessons she was frequently referred to as an example of a scientist at work. In addition, it became clear to me that I needed to introduce even more models of scientists at work; otherwise, many students would develop the notion that scientists work in unpleasant places--the laboratory, the desert. It had not occurred to me when I started this activity that I might be in danger of creating a new negative stereotype of scientists! Again, this illustrates the recursive nature of teaching for conceptual change. It is not a straightforward process of eliciting student conceptions, challenging them, contrasting them with scientific conceptions, and helping students to use the scientific conceptions.

In reality, it is a messier process in which student conceptions are continually elicited, and decisions must be made about which ideas to focus on, to challenge, and how.

The fourth writing activity: Describe a time you felt like a scientist. The fourth writing assignment (see Table 12) was written near the time of the first parent conferences in November. Students were asked to look back over their journals, and as a class we talked about things we had done in science so far this year. We also reviewed our contrasting lists of "Stereotypes of Scientists" and "Important Parts of Scientists' Work" that had been created as a class collaborative-writing task and kept (and used often) for reference typed as a list on the inside back cover of their journals:

OUR LISTS ABOUT SCIENTISTS

Stereotypes of Scientists	Important Parts of Scientists' Work
-Wear white lab coats	-Discover and describe our natural world
-Use tools like test tubes,beakers, microscopes	-Explain the why's and how's of our world
-Are always experimenting	-Ask and seek answers to questions
-Wear glasses	-Solve problems, figure things out
-Are men	-Study
-Have wild hair	-Observe carefully and keep notes
-Are mad, crazy	-Talk to other scientists
-Like to be alone	-Write about discoveries, findings, questions
-Work in a laboratory	-Read journals to find out what other scientists are learning
-Work with poisons, explosives, chemicals	
-Have beards	
-Make monsters	
-Are not old	

Each student was asked to pick one time when she/he really felt like a scientist in our classroom. The selected experience was to be described as a story to share with parents at parent conferences and to share with a visitor to our classroom who was writing an article about our classroom for a teacher newsletter. As teacher, I modeled a story I had written about the central question for the adaptations unit: Are there more different species on the desert or in Michigan? I used my model story to continue to create a community of scientific inquiry, emphasizing how everyone seemed to have changed their mind about their predictions and to have developed better

evidence to support their hypotheses. I ended with: "I really feel like a scientist because I am still wondering about this question and how we could get better evidence to answer it!" As I wrote this story in preparation for the writing activity, my main goal was to use this story to model the form and quality of writing I was expecting the students to create. As I wrote the story, however, I found myself also using the occasion to work on some ideas that the fifth graders seem to be having difficulty with--that in science there is always one right answer that can be proven with one experiment or one source of evidence. Thus, the purposes of the writing assignment expanded from a sole focus on reflecting on personal development as a scientist in this classroom to having multiple purposes: to continue to elicit and challenge students' developing notions of what it means to do science and to provide an occasion for students to connect their investigations of adaptations and plants with their study of how scientists work.

This writing assignment shows some interesting growth in students' conceptions and emotions about science after two months of science study. Nan began by brainstorming over two occasions where she really felt like a scientist. On both occasions she identified involved experiments (with bean plants and grass seeds). Does this mean that she still had a limited conception of scientists as "always doing experiments"? I was captivated by her response, which did not detail the procedures of how we did the two experiments but instead focused on the issues and concepts that we were exploring with those experiments: "The time I was scientists the time that we had a talk about what is food for plants we have some ides but not anufe [enough]. We talk about are evidenc."

She also talks about feeling like a scientist when she puts questions in the class question notebook. This is a science notebook where students record important questions that they raise. It is another kind of writing activity that is used to build the community of inquiry, encouraging and rewarding students for asking thoughtful questions and modeling how scientists use writing to keep track of emerging questions and hypotheses. In addition, the question notebook communicates to students the respect and valuing of their ideas. Nan had quickly become an active participant in our class discussions, a pattern that had not been typical in school because of her

Table 12

Teacher Intentions and Student Responses to Writing Activity 4

Writing Activity	Teacher Intentions
Look back through your science journal and think about the different things we've done so far this year. Pick one time when you really felt like you were a scientist. Write a story about that occasion to share with your parents at parent conferences and to share with Dr. Featherstone who is writing an article about our class.	Help students reflect over their progress and use ideas about science. To help students connect current plant study with earlier discussion about how scientists work. To elicit/assess students' developing notions of what it means to do science - have their stereotypes changed?
Nan	Nathan
plant bens. plant are grass. The time I was scientist the time that we had a talk about what is food for plants we have some ides but not anufe. We tolk about are evidenc. Like whot is the evidenc to the plant that food is. Like food we had toave evidenc to pove that food is some thing you eat I feel like I am a scientis wane I put ? in the book. I feel good a littel but not a lot. I feel like a real scientist. I wiss I was.	A time I rally felt like a scientist was when we h ad a bean esparement. We observed them for 17 day and they have not grown very match. This was a time that I rally felt like a scientist. They weeere a good exspariement for us. We left them in teh sun and only gave them water. that's whay they didn't grow as mutch as in soil and being fertilized. We learnd it has food but not people food like pizza ther food is stuff like fetilzer, sun, and soil. our evidnc that food for plants is not hair because peole don't eat it. We know that liquids like pop and milk are not food for plants because it don't them energey. I like being a scinctisi in our classroom is fun.
Using and emphasizing a richer conception of science - focuses on ideas, evidence, proof, questions. Elicits positive feelings about science: "I feel like a real scientist. I wiss I was."	Using a conception of "being a scientist" that includes more than observing and experimenting: also reasoning, learning, evidence, cooperative nature of scientific work ("we"). Elicits ways he interpreted the bean experiment to support his idea that fertilizer and soil are food for plants.

Table 12 (contd)

Writing Activity

Look back through your sicence journal and think about the different things we've done so far this year. Pick one time when you really felt like you were a scientist. Write a story about that occasion to share with your parents at parent conferences and to share with Dr. Featherstone who is writing an article about our class.

Laticia

observing the beans.
Writing down predictions
Grass plant expreiment
Finding out about Mamib desert organisms
Asking questions
Studied books
Reading books
watching video tapes
Finding structures of plants
Having scientific arguments
Observe and thinking about scientists
class discussions

The time I really felt like a scientist was when we did a bean experiment. We were trying to find out if setan (certain) parts frew or not, and we where measuring the beans all most every day. We were in groups. A person would feed it each cay we came to school. WE also at the end foudn out what grew and what didn't. But soe people said that some broke or it rotted. Some people said they couldn't find some of the parts. I'm very happy that I could be a scientist in this class.

Using a richer conception of "being a scientist": Long brainstormed list before she begins her story.

Elicits positive feelings about being a scientist "in this class".

Elicits a conception of scientific knowledge as jointly constructed in this class ("We were in groups.") - does she see that conception of science more broadly?

Teacher Intentions

Help students reflect over their progress and use ideas about science.

To help students connect current plant study with earlier discussion about how scientists work.

To elicit/assess students' developing notions of what it means to do science - have their stereotypes changed.

Russell

Growing plants and beans to find eficence is fun but I still felt like a scvientist because I think being a scientist should be fun. watching them grow and wondering what gives the food for them too grow and if it is not so fun but, it is mostly fun during the time. Some things that were fun are the drawings, seed, and gre/ass. working with the classroom is fun but there are a couple errors that we make but every body makes error nobodys perfect

Using a richer conception of "being a scientist": finding evidence, wondering, drawing, making errors.
Elicits positive feelings about thismore realistic conception of being a scientist (challenged conception that "real" scientists are boring).
Reflects a change in his conception that real science can't be fun.

Table 12 (contd)

Writing Activity	Teacher Intentions
Look back through your science journal and think about the different things we've done so far this year. Pick one time when you really felt like you were a scientist. Write a story about that occasion to share with your parents at parent conferences and to share with Dr. Featherstone who is writing an article about our class.	Help students reflect over their progress and use ideas about science. To help students conect current plant study with earlier discussion about how scientists work. To elicit/assess students' developing notions of what it means to do science - have their stereotypes changed?
John	Justin
my idea's on WAYS I'VE BEEN A SCIENTIST The time that I felt like a scientist are the times when we have scintific arguments. There fun and I get to find out other peoples idea's on that topic. Some of the arguments that we had are about What is food for plants and can beans garow without soil. We have found out that they can.	We have been doing a lot of things like our bean seeds witch have been complicated to do. and it was fun and we learned that water isn't food Because it doesn't have energy. we have also done a lot with food. WE have been trying to find out if vitemins had energy and they do have energy. We alsolike to find out about juce. We have not found out about juce yet. I want to work with animals and Be eithire a vet or a scientist that works with animals.
<u>Using</u> and emphasizing new aspects of science now: scientific arguments and ideas. Never mentioned lab or experiments.	<u>Using</u> and empahsizing new aspects of science: complicated, finding out, don't know all the answers. <u>Elicits</u> positive feelings about animals and about being a scientist. <u>Reflects</u> ways he interprets a lab activity to support his idea that vitamins contain energy.

speech and language difficulties. By this time of the year, she had already contributed five questions to the question notebook: "Is our food food for plants?" "On the half bean, we want to know where the embryo is." "Is vitamins food for plants and does vitamins have sugar in it?" "If water is not food for us, then what is it for us?" The most exciting part of Nan's story for me, however, was the ending. What a contrast with her statement in September about not liking science or scientists: "I feel good a littel but not a lot. I feel like a real scientist. I wiss I was." In this story, Nan is using a richer concept of science than she began with, emphasizing ideas, evidence, proof, questions. In addition, her story reflects an emerging positive attitude towards science and herself as a learner of science.

Nan was not alone in using a richer conception of what it means to do science. In fact, all six of these students reflected significant growth in their understandings of the important aspects of scientific work. Nathan's story emphasizes more than just the actual experiment he described: he describes learning, evidence, and the cooperative nature of scientific work ("we"). Russell develops the argument that it's OK for science to be fun and still be science. He talks about the fun part as being not only watching the plants grow but also "wondering what gives the food for them to grow." He also comments on errors being a part of science.

Laticia brainstormed a long list of possible occasions to write about before beginning her story about the bean experiment. In her list she included many things other than doing experiments: writing down predictions, asking questions, reading books, watching videos, having scientific arguments. In her description of the bean experiment she does not just describe the steps of what we did, but she focuses on what we were trying to find out. Her ideas that "some people said some broke or it rotted. Some people said they couldn't find some of the parts" communicates a spirit of acceptance of these differences. This was an important insight for Laticia, since she had joined our class late and was the only black student in the class. She felt defensive and worried about making friends and had written once in her journal: "Why are people mean to me? Is it because I'm black?" She had had many hostile encounters with other girls in the class as she tried to become a part of the group. As her teacher, then, I saw a lot more in her story than an outsider

might see. I saw Laticia's willingness to accept disagreements as part of science and not a personal slam against her. Despite scientific disagreements, Laticia reports that she is "very happy that I could be a scientist in this class." I also found her statement and similar statements from other students striking in that they talked about being scientists, not being like scientists (my language in assigning the task).

John's story is interesting in its focus on scientific arguments, which he describes as "fun and I get to find out other peoples idea's on that topic." And Justin's story also describes his work as a scientist as going beyond experiments and focusing on what we learned, what we were trying to find out, what we still hadn't found out about. Note that he also was continuing to cling to his conception that vitamins have energy, an idea which he "proved" to us by finding out that there is sugar in children's chewable vitamins. Since sugar has energy, there is food energy in vitamins, he argued confidently!

All six stories also reveal positive attitudes in our classroom toward science and the scientific community. Both Nan and Justin suggest that they would like to be scientists, yet they both began the year with negative attitudes toward science and scientists. Nan now wishes she were a scientist, and Justin has now connected his love of animals with science: "I want to work with animals and Be ethire a vet or a scientists that works with animals." I am especially struck by these indications of interest in being scientists because the writing task did not ask them to think about the future; the activity was set up as a reflection on what we had done in the past. That students volunteered statements about the future makes them even more powerful statements of attitude.

Looking Across the Four Writing Tasks

This set of four writing activities in the nature-of-science curriculum strand illustrates how a conceptual change model of instruction was used (a) to select appropriate writing activities that would move students forward in their understanding of the nature of scientific work and (b) to interpret students' responses to the writing tasks. The writing tasks served many different purposes, with any given writing task serving different purposes for different students. The

selected writing tasks were not just "neat" writing activities inserted into science. Each task had an important purpose or purposes in developing students' understandings of the nature of science and scientific work. The writing activities were not stand-alone writing assignments. Instead, they were embedded in the larger context of questions being explored, experiments being done. The writing activities were also linked across time, with each activity being revisited to reflect on their changing understandings.

While I had clear purposes and intentions for each writing activity, my responses to student writing (including both written responses and instructional responses) reflected a flexibility and sensitivity to the ideas that students revealed in their writing. The conceptual change model was used as a framework for making instructional decisions and responses to students; it was not used as a lockstep series of steps. There was a constant working back and forth between different phases of the model (eliciting, challenging, contrasting, using). Finally, the development of a community of knowers and doers of science was patiently developed across the three-month period, starting with the responses to the students' initial drawings and continuing through each writing assignment and each classroom activity. Seemingly small steps (stitches) like a comment or a question posed to a student in the journal are critical pieces of what enabled students' growth in understanding of what it means to know and do science.

The writing tasks were not the traditional types of writing in science classrooms. While there were pages of students' journals that were filled with more traditional-looking data sheets and measurements of plant growth, that kind of writing was only a service to other writing tasks that were important learning tools--writing activities that helped students reflect on the data, make new connections, and construct explanations. There were no traditional laboratory reports, no read-and-answer-questions at the end of the text, no lists of vocabulary to define. Instead, writing tasks were selected that were congruent with the norms of interactions in this learning community and that were likely to help students move their thinking along.

Writing as Part of the Living Text of the Classroom

The preceding descriptions of the writing tasks and individual student responses to the writing tasks may give the impression that writing in this science community was primarily a private dialogue between each individual student and the teacher. While this private dialogue was extremely important to students (as reported and emphasized by students in end-of-the-year interviews) in establishing the mutual trust and respect needed to create a learning community, the writing often became most useful as a learning tool when it became public--as it became part of the living text of the classroom.[6] Key features of the learning setting (see Tables 1 and 3) were collaboration, public sharing and revision of ideas, and shared responsibility for learning. Individual writing was a critical strategy to get each student actively engaged and reflective. However, the sharing of this writing seemed to provide an important stimulus for conceptual change.

Over time, a community was established in which students willingly shared their ideas, making their private ideas public. Students developed trust in the teacher and in fellow students to respect their ideas and to challenge their ideas with evidence ("I don't think that could be so, because . . .") rather than judgments ("That's not right!" "No way!").

A lesson that occurred in mid-November will be used to illustrate how individual writing became public and contributed to the creation of a learning community. This lesson took place in a unit about photosynthesis. After several weeks of experimenting and discussion, challenging students' thinking about how plants get their food, I felt like students were ready to hear about photosynthesis: They were now less confident about their entering ideas that water, soil, fertilizer, and so forth are where plants get their food from and seemed really curious now about the role of the sun. I was ready to present the idea of photosynthesis: that plants use nonenergy-containing materials (carbon dioxide and water) and light energy from the sun to make their own food (sugar)

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[6]Corinna Hasbach helped the authors conceptualize this idea of the "living text."

inside their leaves. Before presenting this idea, I wanted students to clarify their current thinking about food for plants so they could see how their ideas compared/contrasted with photosynthesis.

A Lesson Example of the Relationship Between Community and Individual Writing[7]

On November 28, I asked students at the end of class to write about how their ideas about food for plants had changed since the beginning of the unit. Many students, like Nan, wrote things like, "My ideas have not changed." I was puzzled by this response and wondered if they had just forgotten what they had thought before, if they thought it was bad form to admit your ideas had changed, or if they just had not really changed their ideas yet.

The following day I passed out the students' pretests and had them look at what they had written a month earlier about food for plants. Then I challenged them to revisit this same question. In my instructions to them, I modeled ways of being a good scientist; emphasizing that revision of ideas is valued in science:

> KR: I was sort of expecting people to be real good thoughtful scientists. . . . I was expecting to see a more thoughtful answer. Scientists when they get good evidence they are willing to reconsider their ideas . . . change them. . . . I gave you your yellow sheets back [the pretest]. I want you to write to me just as if you talking to me after class or at recess time about whether or not your ideas have changed and why.

In response to this direction Nan carefully read her pretest answer, laughed, covered her mouth in surprise, and put her head down on her desk, giggling. Tiffany, sitting next to her, looked at Nan with a broad smile as if she, too, were amused by what she had written earlier. The students then began to write about how their ideas had changed (or not). As they wrote, I moved around the room reading students' responses (see Table 13) and scaffolding students' efforts to explain and develop their ideas:

KR: [Reading Nan's paper] "I said" . . . what is this word? . . . "but I think water is food and plant food. . .".

Nan: Yeah. Why do they call it plant food if it's not food?

KR: O.K., why don't you add that to your answer?

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[7]Constanza Hazelwood identified this lesson example as an interesting one to illustrate community vs. individual writing.

"Why wond the[y] call it plant food if it isn't food?" Nan's question about plant food is a private response to a public debate: She recognizes that other students have become convinced that plant food (fertilizer) is not food (because it does not contain any calories or food energy). She also recognizes that many classmates now believe that water is not food for plants. But that still does not seem to make sense to her. This writing task served an important function in helping Nan recognize that this confusion remains (in contrast with a day earlier when she simply stated that her ideas had not changed).

In contrast with Nan, some students had significantly changed their ideas at this point (Table 14). Julia, a successful, school-smart student who was hesitant to ever admit she didn't know things, recognized that her earlier idea that different plants can have different kinds of food "was wrong." As I talked to her individually about her thinking, I encouraged Julia to write more about her idea. She then added to her written response that she thought the one thing plants eat is sugar, but admitted that she was not certain what that sugar really is. As her teacher, I was delighted to see Julia using writing to wonder on paper and to see her willingness to admit uncertainty. Nathan used this writing to explore a developing idea that sun might be food for plants. He proposed two alternative explanations of a grass plant experiment to argue two possible positions. Matt was the only student who linked this question about food for plants to our earlier study of bean seed embryos and cotyledons. He wrote that "the cotyledon is food for a seed." He's still not sure about the "white foamy things" in soil that you buy at the nursery. Perhaps they are sugar? As I continued to read students' individual entries and talk to them individually, I commented to Matt, "Oh!! That's a good one. I don't think anybody else thought to put that in there."

As Laticia was writing, she called me over to ask, "Is sun food for plants?" At this point, I pulled the students away from individual writing into a whole group discussion:

KR: Oh!!! We have a good question here. Let's come back together as a group right now. As Laticia was writing, sometimes this happens when you're writing, thinking about your ideas, you come up with some new questions and realize you're not sure about some things. What was your question, Laticia?

Table 13

Writing Samples
Science Lesson 11/29/91

Writing Assignment

Look at what you wrote on your pretest about food for plants.
Have your ideas changed? Explain

Student Responses

NAN: Dera Dr R My ides have chandged a lot I said wather [water] I do not now whot is food for plants but waher [water] is food for plants and plant food. Why wond the call it plant food if it isnt food. from Nan

Nan, Listen really carefully to the new evidence we get next week! I want you to really think carefully! Good job today. Dr. Roth

---

NATHAN: Dear Dr. Roth I'm still suher [sure] fertilizer is food for plants because it gives it energy. I also stil think sun is food for plants because of the grass plants the ones in the dark were yellow and the ones in the light are green. But I still not shere [sure] that the sun is food for plants because I thank that they did not have enough air to live so it turned yellow.

Nathan, Super job of explaining your thinking! Dr. Roth

MATT: Dear Dr. Roth My Idiea have changed al lot I guess I think that sun is for a grownup plant and a cotyledon is food for a seed. I not sher [sure] about those white foamy things [in the soil].

Matt, I'm glad you remembered about the cotyledon - no one else brought that up but everyone agrees! Dr. Roth

---

JULIA: Dr. Roth what I put was wrong because I said food can be <u>anything</u> which is not true, and I put that since there are so many plants that they all eat something different, and I think food for plants is basically just a certain thing with sugar (which I don't what that is but that's what I think).

Julia, Do you think all plants have the same kind of food? I like your idea about the sugar! Dr. Roth

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Laticia: Is sun food for plants?

KR: Is sun food for plants? That's what she started thinking about. And I think I saw that on several people's papers that they're thinking about sun right now. Because of the experiments we did, the sun seems to be really important. Laticia, would you make sure we get that in the Question Book?

At this point in the lesson Laticia's private writing becomes public not only as part of the discussion but also in written form in the Question Notebook. This notebook was always available for students to look at during free time, and it was a book that we revisited as a class to see if we could answer questions we had posed. At the end of the adaptations unit, someone in the class suggested making a bulletin board for the school showing what we had learned. Jesse used his own free time and recess time to copy all the questions to date onto large poster paper to hang on the bulletin board. He decided to arrange it so that students could mark their guesses on the poster paper, and that later the answers we had generated would be posted. Although Jesse never got quite enough support from me to completely pull off this project, it is an example of ways in which private ideas and writing became public within our classroom community and sometimes beyond the bounds of our four walls.

Returning to the November 29 lesson, after some continued discussion about the sun, I pointed out something about Matt's writing:

KR: I think I read everyone's, and on Matt's he wrote something that I don't think anybody else had. Read your answer, Matt.

Matt: I think that sun is food for a grownup plant and the cotyledon is food for a seed.

KR: Did anybody else put cotyledon for the seed? [Pause] Does anybody else agree with him that the cotyledon would be food. . . . How many people agree that the cotyledon would be food for the embryo? [Everyone in the class raises hand]. OK, let's add cotyledon to our list [of hypotheses about food for plants]. We don't have it up there, do we? [KR walks towards the chart in the corner of the classroom and writes the word "cotyledon" at the bottom of the list of hypotheses about food for plants.] It's a hard one to spell. [As students try to help me spell it.]

In this interaction a suggestion taken from Matt's individual writing became part of the text of a class chart that was constructed by the students across the unit on food for plants. The other hypotheses on the list had each been suggested by class members at various points during the unit.

After cotyledon was added to the list, the discussion moved to evidence that we had to "prove" that suggestions on our list were or were not food for plants. This was not the first time that the list had been analyzed in this way. Students would come up with examples of evidence and present them to the class. If no one objected to the logic of the suggestion, the student would write her or his idea on a yellow stickie and post it on the part of our chart labeled "Evidence." By the end of the unit we had so many stickies that we had to go off the bulletin board chart and post them around the corner wall and onto the closet doors.

After we finished posting new evidence on the chart, the lesson concluded with another vote. Students were asked to vote for those things that they now thought were food for plants:

> KR: Now we're going to take the vote, but before we do would you look at what you wrote down yesterday? I want you to only vote for those things that provide energy for plants. And if you want to add anything that you didn't put down yesterday add it right now. We're going to take a vote. Today is November 29 [writes date on chart]. [Pause] How many people <u>today</u> think fertilizer is food for plants?

The videotape of the students shows many of them writing in their journals--many adding ideas about sun and/or the cotyledon. Thus, ideas started by Matt and Laticia became public and then became part of many students' thinking and writing. During the voting, students publicly committed to their ideas as I recorded on the chart the number of students voting for each hypothesis. In this process, the students successfully negotiated for a new category of vote--a vote of uncertainty. You could now vote for things you were sure were food for plants, things you were unsure about, and things that were not food for plants. My reaction to their suggestion was that since scientists are often unsure, it was a good idea for us to have an "unsure" category. Students did not make fun of each other's votes but seemed instead genuinely interested in how our voting had changed since the beginning of the unit. Students were also struck by how there were no items that everyone agreed on, until we reached the bottom of the list:

> KR: How many people think the cotyledon is food? [All students raise hands]. 1, 2 . . . 21. All right!!! We all agree on something.
>
> Chorus: Yeah!!!!

There was a tremendous sense of celebration in that outburst of cheers. I sensed a feeling of genuine accomplishment--that we had patiently considered all these different hypotheses over the past month, explored carefully sources of evidence, and found at least one satisfying answer that made sense to all of us. This cheering for ourselves and our learning and consensus-building seems to me to communicate the essence of this learning-centered community. We were not cheering for one student's outstanding performance or for an impressive product that we had created. Instead we were celebrating a somewhat messy-looking chart that symbolized for us the collective growth and learning we had shared in creating it. Certainly, this was a moment when knowledge was being cooperatively constructed within a scientific learning community.

During this lesson, lines were blurred between private writing and public writing. Private writing became public when Laticia's question about the sun was discussed and put in the Question Notebook and when Matt's idea about the cotyledon was added to the class chart. Public writing became part of private writing when students were given a chance to add new ideas to their lists of food for plants before the vote was taken. Many students added Matt's ideas about the cotyledon and Laticia's ideas about the sun at this point. Students were encouraged to use ideas from their classmates, and were not penalized for using others' ideas. The goal was learning, and competition among individuals did not have a place in this community. The goal (and celebration) was for everyone's understanding, not just for the quickest or most scientifically oriented students.

Teacher and Student Roles in Structuring Writing Tasks in Science

While most of the writing tasks in this unit were carefully selected and structured by me as the teacher in order to encourage and support conceptual change, this does not mean that students never generated their own ideas of writing activities. I have already mentioned how students got involved in planning a bulletin board to illustrate what we had been studying and learning. One idea students had was to do some drawings of stereotypes of scientists and scientists that don't fit the stereotype. All pictures would be put on the bulletin board, and passersby would be challenged to identify which were scientists and which were not. Tiffany and Russell drew pictures of stereotypes of scientists, copying their pictures in their journals from the first day of class. Other

pictures showed scientists at work in many different settings (ice floes, in the woods, in a room at home, climbing a cliff, at a volcano) and showed scientists doing many different kinds of activities, including pictures by Allison and Nathan that featured scientists writing.

Many students were excited about setting up their own personal experiments with the grass or bean seeds. About half the class pursued an experiment idea on their own time. I supplied needed materials and support during recess times. Other students took materials home to do experiments completely independently. One recess I asked the group who had stayed inside to think about how they might go about doing a good written description of their experiments. I typed up a form using the categories they had defined and made them available to students. Although they were never required to write about these experiments, Tiffany, John, Michelle, Annie, and Heidi each wrote up their experiments using these forms. In addition, Tiffany, a student who had been held back a year and received resource-room help with reading, kept informal notes in her journal about her experiment as it progressed.

Thus, writing activities in this science classroom at the beginning of the year were often structured by the teacher. However, independent choice about writing was encouraged and supported. I tried to balance students' interests in defining and exploring their own questions that enabled me to do more modeling and supporting of scientific thinking. My goal is for students to become more and more able to explore questions of their own, but I want them to be able to explore questions in ways that will lead to new understandings and more scientifically appropriate explanations. To achieve this I need to scaffold their thinking. Writing activities play a critical role in this process.

Functions of Writing in Science for Teacher and Students

As teacher, my main instructional goals were to support students in learning science concepts and in understanding the nature of science. The writing assignments were used as a tool to get students to share, try out, examine, contrast, and revise ideas; students were expected to wonder and ask questions on paper. The writing enabled me to better understand each student's thinking. I could use this knowledge instructionally, both in my interactions with individual

students and in whole-class discussions. Through the written dialogues with students in their journals, I was able to have conversations in which I could make comments and ask questions that were tailored to the individual student. The students' writing about their ideas also helped me shape whole-class interactions in ways that were responsive to student thinking. These functions of student writing for the teacher stand in contrast with the kinds of writing I used to do which served the function of holding students accountable for completion of work and enabled me to grade them "objectively." However, I did not in the past use writing to reveal student thinking and to guide planning and teaching.

For students, writing served a variety of functions. Writing stimulated students to clarify and articulate their positions and ideas. Once these ideas were written down, they served as a still image of ideas to be preserved and examined at a later date. As students interacted with new ideas and experiences, they revisited their ideas and revised them. That preserved, written image representing their ideas helped students integrate new ideas with their prior knowledge and supported them in tracking and more clearly articulating their developing understandings. Thus, for students, the writing helped them elicit their ideas, contrast their ideas with those of others, and helped them build onto and change their ideas. As pointed out in the analysis of the examples of student writing, it was not always predictable which function a particular writing task would serve for a particular child. And a given writing task was likely to serve multiple functions for each child. For example, every writing task, no matter what its intended function by the teacher, elicited information about students' ideas and thinking.

Writing was used to extend and support the overall inquiry process regarding the nature of science and science concepts. It was an integral part of a series of activities that were all focused on supporting the conceptual change process, in such a way that the talk surrounding the writing was as important as the writing itself. Writing activities did not consist of a collection of "neat assignments" plugged into a science unit but were connected to the inquiry process. The writing emphasized the tentative nature of ideas, the need for reexamination and revision of ideas. By

having students write about the same topic, the learning community could share and debate the ideas they were writing about, and the teacher could support the examination and debate.

Realizing the Shared Vision of a Learning-Centered Classroom

The fifth graders in this classroom participated in different kinds of writing in the context of learning science. To what extent are these kinds of writing experiences consistent with the shared vision of a learning-centered classroom we portrayed earlier (see Figure 1)? To what extent do they contribute to the creation of a science learning community? To what extent do they support student conceptual change?

Compared with the writing I have had students do in the past, the writing I had the students do this year was much more consistent with the qualities of the learning place and much more embedded in the science learning community. The writing was much less a product for evaluation and grading purposes and much more a tool to support thinking and sense making. This writing was much more personal--Nan's initial dislike of science and her willingness later to change her mind about scientists and state that she wishes she could be a scientist is an example of writing that reveals a personal, emotional involvement. I would never have seen such statements in the lab reports and tests that students used to write for me. For me? That is another difference in the writing of these fifth graders. The writing in this science class was not so much written for me but to me. It was more like a conversation starter between myself and the students in the journals and then among all of us as ideas from the writing became part of the class discussion. There was a stronger sense of ownership, commitment, and shared responsibility by each member of the community. In the future, I would like to make this ownership issue even stronger and more genuine.

Likewise, active inquiry and question asking about science concepts were valued and encouraged by the kinds of writing tasks completed in this science unit. Most student writing tasks included an explicit request or direction for students to generate questions and to wonder on paper. Learning was both public and private, and expertise came from members of the community where everyone's ideas were valued and respected as useful in the learning process. Evidence, not

authority, was used to judge the merits of ideas or the quality of a piece of writing, and students were "good learners" when they listened and responded to each other in thoughtful ways. Celebration of the learning process and ideas took place regularly. Finally, each learner started and finished in a unique place in the learning process, and diversity among learners was valued and appreciated. It is interesting that I found it extremely difficult to assign students report card grades. Instead, writing became a more important communication tool that enabled me to capture important aspects of each child's growth and change in science (see Appendix for letters written to parents of the six students discussed in this paper). This kind of feedback required more patience and reflectiveness on my part than simply assigning grades. But such feedback seemed to be more consistent with the qualities of this science learning setting that were being patiently stitched into the learning community over time.

It has been the collaborative nature of this teacher/researcher study that has convinced me of the importance of studying and talking about the nature of the learning community in science classrooms. As I studied and drew from the literature on conceptual change approaches to science instruction in the past, I made many assumptions about how ideas about "student misconceptions" and "discrepant events" would need to be used carefully and caringly in classroom settings. But this research has pushed me to articulate these assumptions and to describe more fully my conception of conceptual change teaching. In my current conception of conceptual change teaching, the learning-centered classroom community is an essential core. A conceptual change framework for thinking about my planning and teaching (eliciting student ideas, challenging their ideas, contrasting their ideas with scientific explanations, and engaging students in using new ideas in a variety of contexts) remains a helpful one that keeps my attention focused on learners and their developing understandings rather than on the content to be covered. But this framework will not make a difference if it is merely inserted into a work-centered classroom or if it is expected to create beautiful quilts of understanding overnight. The quilting process requires a patience that we are not used to in our technological, instant society. Creating learning-centered classrooms where

students develop meaningful understandings of science and science concepts requires a similar patience.

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Appendix

Letters Written to Parents about Student Progress in Science

SCIENCE INTERIM REPORT
January 31, 1991

Russell is an excellent science student! He listens carefully and really tries to make sense of the experiments we do. He is not willing to just memorize definitions. He is a good contributor to our whole class discussions and in small group work. He asks questions that are thoughtful and records these in our class Question Notebook. This is a notebook where we keep track of the best science questions that students ask. Russell asked one day, for example, "What do worms eat in the soil?" He thought of this question when we found out that soil does not contain food energy, so he started wondering beyond that: If the worms can't get energy from the soil itself, what do they eat? I have been emphasizing that this is exactly the kind of thinking and questioning that good scientists do.

Russell's unit test shows that he developed excellent understandings of the concepts we studied about how plants get their food by making it during photosynthesis. He understood these concepts well enough to use them to explain new real world situations posed in questions #4 and #8. His predictions were accurate for these questions, and he was able to use the concepts of the seed's cotyledon and photosynthesis to explain them. You will notice that he writes very brief answers and that I had to ask him more questions to get him to explain what he knew in his head. This is a typical problem Russell has in his science writing. I have been encouraging him to write complete scientific explanations that tell why and how.

His word picture for Part I shows that Russell is able to connect together a number of complicated and abstract science concepts--energy, food, photosynthesis, embryo, cotyledon, chlorophyll, etc. His oral explanation of this word picture was impressive! It is not easy for fifth graders (or older students!) to understand concepts which they cannot see happening. They have to imagine what is going on inside the plant, and Russell does an excellent job with this.

Russell has made wonderful contributions to our science class. He works diligently and is usually actively involved in his science learning. I hope he will continue to use his abilities to continue to grow as a young scientist!

SCIENCE INTERIM REPORT
January 31, 1991

I am very excited about Laticia's growth in science! She has become an active participant in our scientific arguments. These are discussions in which students have to use evidence from experiments to defend their hypotheses. Laticia was very quiet in class at first, but now she is an eager participant. Her questions and comments demonstrate that she is following the discussion closely and really trying to make sense of the quite complicated ideas we have been studying. Like a good scientist, she is always trying to figure things out and not just memorizing definitions and facts. Laticia has contributed quite a few thoughtful questions to our class Question Notebook. This is a place we keep track of good science questions that are asked by students. Some of Laticia's questions were: "Is sun energy for plants?" "Does the adult plant have more than one baby plant (embryo) inside the seed?" "Is sun food for plants?" In asking these questions, she was thinking in each case about an experiment we had done and puzzling about how to interpret the experiment or how to take it a step further.

Laticia's unit test shows how well she understood the concepts we were studying about plants and how they get their food. I was especially impressed by the ways in which she was able to use her knowledge to explain new real world situations. For example, on question #4 she made an accurate prediction and then supported her prediction with the concepts we had studied about the seed's cotyledon and about plants' making of food during photosynthesis. She gave a complete explanation without needing prompts from me to tell more. This was unusual in the class! This kind of question is difficult for fifth graders (and even older students), and I am proud of what a great job Laticia did.

Laticia was also able to see how the many concepts we studied were connected to each other. On the word picture (Part I) she put the concepts in groups in a way that emphasized that air, sun, and water alone are not food for plants but that mixed together they make sugar which is food energy for plants. This is a very abstract set of concepts--students cannot actually look inside plants and see it happening. They have to imagine it happening in plants. Laticia has done an excellent job of this.

Laticia is also extremely eager to cooperate and focuses her attention on her science assignments. Occasionally, she has trouble working in a small group on an experiment and needs some support in figuring out how to involve everyone in the group fairly. This is an area I would like her to keep working on--it is another important quality for scientists to have.

It has really been a pleasure to teach Laticia science. She has an enthusiasm that is a wonderful contribution to our class, and her cheerful greeting to me each day and her frequent polite offers to help are much appreciated.

SCIENCE INTERIM REPORT
January 31, 1991

I've enclosed a copy of Justin's revisions of his plants and photosynthesis unit test, because it shows how he is willing to keep changing and improving his explanations of science phenomena. It is also exciting for me to compare this unit test to a pretest he took before the unit. Since the pretest, Justin has developed much more complicated ideas about plants and is able to connect those ideas together in sensible ways. Look at how he was able to put concepts together in meaningful ways in the word picture he created for Part I of the test. His answer to test question #4 in Part II shows that he is also able to use the concepts he has learned (about the seed's cotyledon, about photosynthesis, etc.) to explain real world situations. This is not an easy task for fifth graders (or even older students!).

Another thing that the test shows is Justin's development in writing in science. At the beginning of the year, Justin wrote very short sentences and did not often develop complete explanations. His writing on this test and in his journal has gotten much more thoughtful and complete. I hope he will continue to develop his ideas fully in his science writing. I encourage him to write down more of what he is thinking. I think he used to worry about putting down some of his ideas, because they might be wrong. We have emphasized that scientists often write and think things that later are shown to be wrong. But it is important that scientists share their best thinking at the time--this is how knowledge grows in science and in fifth graders, too!

During class Justin is an eager and thoughtful participant. During the unit on plants his questions and confusions showed that he was genuinely trying to make sense of the ideas we were studying instead of just taking my word for it. For example, he was not convinced that fertilizer or "plant food" you buy at the store does not contain food energy for plants. He was persistent in trying to find evidence that would help him understand this idea. He often made me laugh with this, because I thought I was giving such convincing evidence. But he always had a critique of my evidence--he was being an excellent scientist!

SCIENCE INTERIM REPORT
January 31, 1991

Nathan is doing excellent in thinking in Science class. I have seen a lot of growth in the quality of his work and in his confidence in science. He is a good, careful thinker, and I have been delighted that he has begun to share his ideas and questions more often during our science discussions. He is one of the contributors to our Question Notebook in science. In this notebook we record good questions that students raise that show they are really thinking about the concepts. One of Nathan's questions was stimulated by the concept that soil does not contain food energy for plants. He wondered: Why do people plant trees in soil (if it is not food for them)? This kind of thinking and questioning is important in science, and I have tried to encourage Nathan to keep asking such questions and to keep looking for evidence to support his ideas.

Nathan does an excellent job working on experiments and projects in his small group. He does not waste time and gives his full attention to the task at hand. He is a cooperative group member and contributes ideas that help the group do productive work.

Nathan does a conscientious job of writing about his ideas in his journal. I have been trying to support him in improving the quality of his science writing. He is improving his science explanations. For example, on the unit test he wrote a long and complex response to question #4. You can see that I still encouraged him to clarify his answer, but I was impressed with how well Nathan was able to use the ideas we had studied to make a prediction for this problem and to explain that prediction using concepts about plants' making of food. This is not an easy task for fifth graders (or even older students!).

Nathan's test showed that he understood many concepts we had studied about how plants get their food. He was able to construct and explain orally a rather complicated word picture for Part I. This word picture and his explanation of it convinced me that he was not just memorizing words he had heard in class--he really understood the concepts and was able to connect them together in meaningful ways.

Nathan is a delight to have in science class. My only frustration is that I don't hear from him as often as I'd like during class discussions--he has such good ideas and questions to share!

SCIENCE INTERIM REPORT
January 31, 1991

I am very excited about Nan's efforts and progress in Science. She is an active and eager participant in science activities, and she contributes excellent ideas and questions during our class discussions. In fact, she is one of the most frequent contributors to our Science Question Notebook. This is a notebook where we record good questions that students raise--questions that show they are thinking like scientists. Some of Nan's questions during this last unit on plants and how they get their food were: "Is air food for plants?" "Are vitamins food for plants?" "Do vitamins have sugar?" "If water is not food for us, then what does it do for us?" These questions and many others show that Nan is listening carefully in class, thinking about the ideas and evidence we explore, and trying to genuinely make sense. She is not satisfied to just memorize some definitions; instead, like a good scientist, she puzzles about things and looks for convincing evidence and explanations to help her figure out if air is food for plants or why people need water if it is not food.

Nan's unit test showed that she developed a solid understanding of the central concepts of the unit on plants and their food. She still is confused about some of the concepts, but she understands the most important concepts well enough to use them to explain new real world situations. For example, on test questions #4 and #8 she was able to make an appropriate prediction and to use ideas about plants' making of food to support her prediction. As you can see from my questions to her, I am trying to help her develop as a writer in science by encouraging her to give more complete explanations. On the last bonus question at the end of the test, for example, I am sure that Nan has in her head a much fuller explanation of why Christmas trees die after they have been cut. She can talk about why plants need roots to get water to help them make their food. However, her written answer did not capture this knowledge.

A question that was difficult for Nan was Part I, the word picture. This required students to take a random list of terms we had studied and to connect them together to show how they fit together to explain how plants get their food. Nan's word picture and her oral explanation of it to me revealed some confusions about the concepts. This was a very difficult and complicated task for fifth graders. I think as Nan gets more experience in making such connections, she will improve her ability. One thing I noticed in watching her work on this task is that she very quickly created a word picture and then would not change it. I hope she will learn to approach tasks like this a little more slowly and be willing to change and revise her ideas.

I have thoroughly enjoyed working with Nan. I think she is doing wonderful work in Science, and her success is even more remarkable since she often missed parts of science lessons when she was working with the speech teacher. I am impressed with how seriously and enthusiastically she approached her Science studies. She has been a terrific scientist in our class!

SCIENCE INTERIM REPORT
January 31, 1991

I am excited with the ways in which I have seen John grow this year in his scientific thinking and in his attentiveness and cooperation in science class. Early in the year, John seemed to be easily distracted by classmates and not very involved in our science activities. What a change I have seen! Now he eagerly participates in science class discussions and is a leader in helping his small group stay focused on the task at hand. John even gave up a couple recesses to conduct an experiment he designed and to help create a science magazine idea for our class. He was the first student to use the form we created to write up his experiment (on his own time!), and he shared this report with the whole class. This kind of initiative shows that John is developing important science skills--he is curious, seeks answers to his own questions from experimental evidence, is willing to share his ideas with others. Bravo for John!

John's unit test shows that he developed a solid understanding of the central concepts of this unit. The word picture he created (Part I) shows how he was able to connect together a lot of concepts about plants (photosynthesis, sugar, energy, chlorophyll, embryo, cotyledon, fertilizer, etc.) into a coherent explanation about how plants get their food. I have been emphasizing the importance of making sense of scientific concepts, not just memorizing terms. John's oral explanation of his word picture provided evidence that he was genuinely making sense and not just memorizing words I had said. His efforts to <u>use</u> the concepts we studied to explain new situations also shows off his good understanding. For example, on test question #4 (Part II), he made an accurate prediction and then was able to use ideas about food in the cotyledons and about photosynthesis (plants make food) to explain his prediction. You will notice on this question that I had to support him in creating this explanation by asking him to write down <u>why</u> and <u>how</u>. John needs to keep working on developing complete scientific explanations that tell why and how.

I thoroughly enjoyed working with John in Science. His eagerness, enthusiasm, willingness to be helpful, and his sense of humor made wonderful contributions to our science class!